The War Underground 1914–18

Tactics and Equipment

SIMON JONES

ILLUSTRATED BY ADAM HOOK

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THE WAR UNDERGROUND 1914–18

TACTICS AND EQUIPMENT

INTRODUCTION

Beneath the trench warfare of World War I there took place a largely hidden and secret struggle for ascendancy and survival. The opposing sides attempted to tunnel under no man's land to place explosive charges beneath the enemy's trenches, perpetuating and escalating the ancient method of military mining to a scale of effort, ingenuity and destruction never surpassed before or since. Underground warfare also meant seeking refuge from lethal and overwhelming shellfire in dugouts and tunnels, which accommodated troops for counter-attack or secretly massed them for assaults, as well as housing headquarters and support services. The following pages describe these varied facets of a vital aspect of the war of 1914–18.

UNDERGROUND WARFARE BEFORE 1914

Attacking a fortress by digging a tunnel beneath its walls to destroy them was recorded as early as the 9th century BC. From the 15th century, gunpowder replaced the burning of wooden props soaked with tar or pig fat as the means of bringing about the collapse. Military mining came to be defined as the driving of tunnels in order to place explosives for the destruction of an objective. Mining would be carried out in combination with sapping, the digging of zigzag trenches or 'parallels' as close as possible to the walls of the fortress, from which mining would be commenced. The depth of tunnels might be no more than 6m; they would be as short as possible owing to difficulties in ventilation, while their cramped dimensions required the use of small-sized tools. The prevention of a mining attack required the use of counter-mine tunnels from which the defenders could listen for the approach of attack tunnels and, when they were close enough, fire explosive charges to destroy them. Such charges, which were too small to form a crater on the surface, were known as camouflets. By the mid-19th century, three centuries of experience had established the science of military mining as an integral part of siege warfare. In terms of tactics, technical details of calculations of size and depth of charges, equipment and requirements of personnel, military mining was the subject of detailed manuals and courses of instruction.

Depicted in an 1856 watercolour by William Simpson (1823–99), these Russian mines beneath the Bastion du Mât, or Flagstaff Bastion, Sevastopol, Crimea, were captured by the French in 1855. Their layout, small dimensions and close-timbered construction followed long-established practice. Both attackers and defenders used clay levels for tunnelling, which dictated the depths of the main Russian defensive galleries at 8m, and an additional system at 17m. The French were unable to advance their tunnels beneath the bastion and an intensive underground struggle of mines and camouflets took place 500–700m away from the Russian fort. (Yale Center for British Art, Paul Mellon Collection)

The Crimean War (1853–56) saw an unprecedented increase in the scale of military mining in terms of the depth and size of explosive charges fired. The Russian defence during the siege of Sevastopol involved firing some 20 mines of between 550kg and 2 tonnes, with preparations for a charge of 4 tonnes at a depth of 15m. During the second half of the 19th century, however, mining fell out of favour, as it appeared that fortresses could now be destroyed by the increased destructive power of artillery, and it would not again be necessary to lay siege to them. Military mining declined and 'miner' was dropped as a specialism in the military engineer corps of Germany and Britain.

While permanent fortifications were regarded as being too vulnerable to artillery, there were signs that the increased strength of field defences, due to the combined defensive power of long-range rifles, machine guns and barbed wire, might require attack by military mining.

Union forces laying the Petersburg mine during the American Civil War (1861–65). The Petersburg mine of 30 July 1864 was aimed at a strongpoint and gun battery in the Confederate lines. A 156m gallery was driven by the 48th Pennsylvania Infantry, commanded by and composed mainly of coal miners, firing a 3,628kg charge of gunpowder that killed 250–350 Confederate soldiers. The subsequent Union infantry assault was mishandled, however, with the result that the attackers were trapped in the crater by a counter-attack. In respect of its use against entrenchments, the contribution of civilian expertise, and the tactical errors made, the Petersburg mine was a portent of the nature of military mining in the coming world war. (© CORBIS/ Corbis via Getty Images)

The detonation of a Japanese mine beneath the caponier of North Kikwan or Fort II at Port Arthur (modern-day Lüshunkou), during the Russo-Japanese War, 26 November 1904. During their attacks on the Port Arthur forts, the Japanese reportedly used dynamite explosive, which was many times more powerful than gunpowder, firing charges as large as 5 tonnes. This particular mine was the signal for a Japanese assault that was not successful. (INTERFOTO/ Alamy Stock Photo)

In the later 19th century, the French Army in particular incorporated new developments in mine ventilation and mechanized excavation into its mining manuals. By the beginning of the 20th century, however, progress in civilian mining practice had far left behind military mining. This was evident in the sheer scale of the civilian mining industry, the vast size and depth of mines, the degree of mechanization and the technical knowledge of qualified mining engineers, in particular in geology, surveying, ventilation and dewatering. The scale of industrial accidents underground, often the result of explosive and noxious gases, brought with it the use by the more enlightened mine-owners of new self-contained breathing apparatuses. The practice of military mining, however – shallow, small dimensions, close-timbered, with the use of gunpowder as the standard explosive for mine charges – remained much as it had been 100 years previously (Jones 2010: 13–28).

The Russo-Japanese War (1904–05) saw mining used extensively against both permanent and field fortifications. At Mukden (modern-day Shenyang), in a portent of the trench warfare of 1914–18, stalemate prevailed on a 64km front during the winter months, with opposing lines of trenches and barbed wire separated by a no man's land in places less than 100m wide. Mining was resorted to, even though its impact against such linear defences might only be local and indecisive (Lazard 1932: 118–19).

The Russo-Japanese War prompted a revival in siege-warfare exercises and the issue of new regulations by European armies. In Britain, a large-scale exercise held at Chatham, Kent, in 1907 was the first since 1887, though the subsequent exercise, held in 1913, was on a far smaller scale. The new regulations were accompanied by assertions that the conditions of the Russo-Japanese War would not be allowed to pertain in a future war. The German regulations attempted to forestall the development of extensive mining, scaled back the regulations, and advocated underground attack only as a last resort.

In 1910, the British manual *Attack and Defence of Fortresses* asserted that all fieldworks could be taken by infantry assault. Informed voices in European armies, however, including Lieutenant-Colonel Robert N. Harvey, the Chief Instructor in Fortification at the British School of Military Engineering, suggested that trenches and barbed wire, when protected by modern small arms, could now be so resistant to assault that mining would have to be used to capture them (Harvey 1914: 217).

MILITARY MINING 1914–15

In 1914, predictions that mining would be employed to overcome entrenchments were proved correct. When the German attempt at encirclement of the French armies was defeated at the Marne in September 1914, the Germans dug in along the Aisne River and static warfare spread along a line from the Swiss border to the North Sea. The difficulty of dislodging the enemy from trenches protected by barbed wire, rifles and machine guns, especially owing to a shortage of heavy howitzers capable of destroying the positions, meant that by November mining was also being tried at many locations from the Vosges mountains to Flanders. If one side started mining, the other was obliged to defend against it and, once begun, it was difficult to stop. Early mining attacks were little more than shallow tunnels or covered saps, driven from the ends of surface saps dug across no man's land in conditions of great danger. On 13 November 1914 in the Argonne, the German 3. Rheinisches Pionier-Regiment Nr. 30 used a 40kg charge placed in a shallow tunnel to create a 6.5m-diameter crater in the French lines that the Germans immediately consolidated (Witte 1928: 39–40).

On 20 December 1914, a similar attack was staged on a larger scale by the 1. Westfälisches Pionier-Bataillon Nr. 7 at Festubert in Flanders, using hand-borers to place 50kg charges at the end of ten covered saps against the section of front line held by Britain's Indian Corps (Buhr 1938: 119–22). The Germans succeeded in taking both the front and second lines, claiming to have

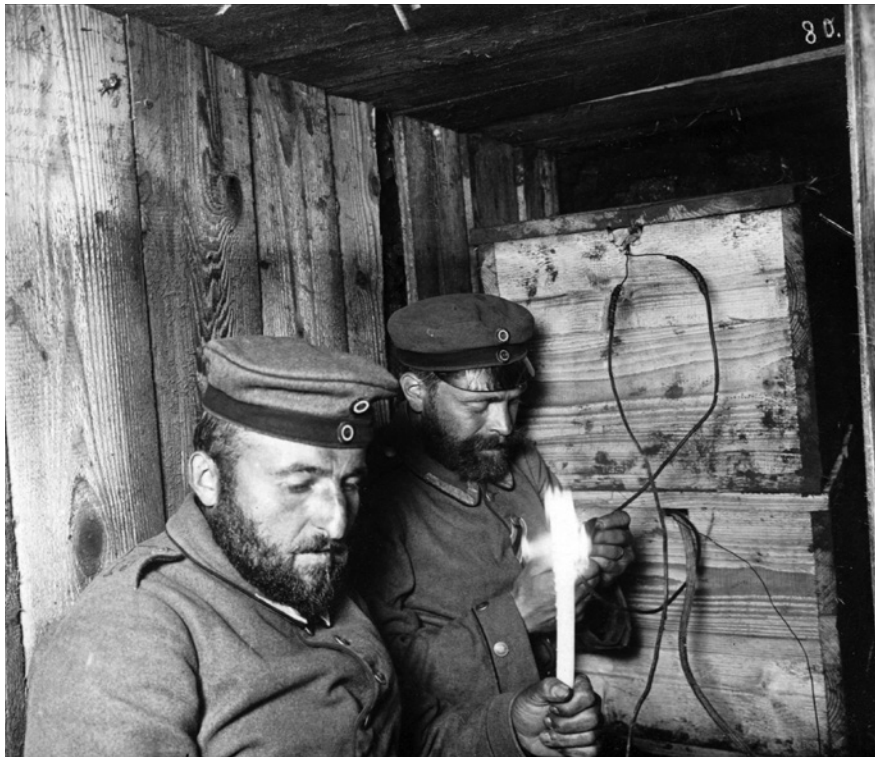
Men of Pionier-Bataillon von Rauch (1. Brandenburgisches) Nr. 3 at a tunnel entrance in 1916. The hand-borer could be used for placing camouflet charges to destroy enemy tunnels, for shot blasting, and was also used in early attacks against trenches. (Author)

captured 19 officers and 815 men. The attack was a disaster for the British, who lacked the siege-warfare equipment and troops to prevent the attack.

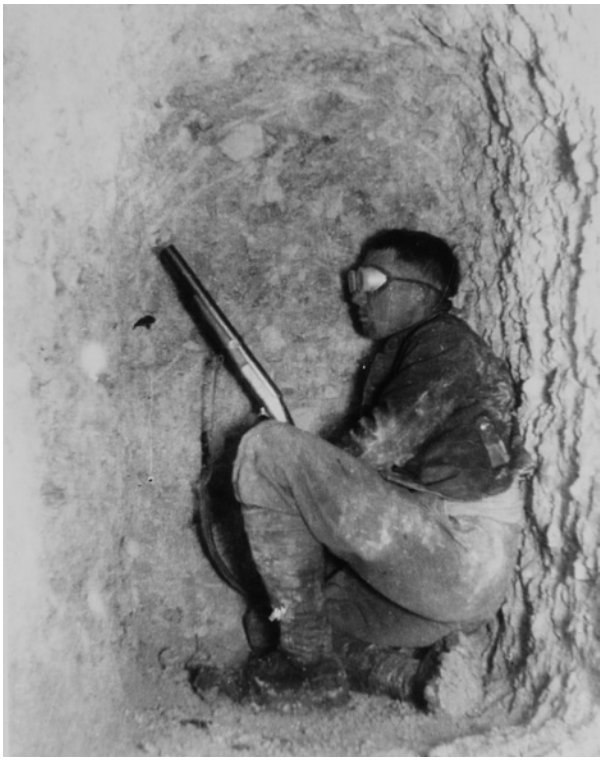
The French were also actively mining, for example achieving success at Hill 200 in the Champagne sector when, at 1300hrs on 8 December 1914, the 34e Division d'infanterie fired three mines in combination with an infantry and artillery attack, enabling it to take and hold the German front line.

In December, French and British commanders at the front requested more engineer units to deal with sapping and mining attacks. On 21 December, Général Ferdinand Foch, commanding the Group d'armées du Nord, wrote to Général Joseph Joffre, the French Army chief of staff, requesting that new units be recruited that need only be trained in sapping and mining. Two days later, Général Fernand de Langle de Cary, commanding the 4e Armée in the Champagne, also requested more engineers for this purpose. Joffre converted reservist territorial engineers into sappers and miners and authorized the formation of auxiliary engineer companies from suitable personnel of other arms (Service Historique 1931a: 609). Lieutenant-General Henry S. Rawlinson, commanding the British IV Corps, asked for a special battalion for this same purpose, a request supported shortly afterwards by Lieutenant-General Sir Douglas Haig when he became commander of the First Army. At the same time, the British Expeditionary Force (BEF) began to form brigade mining sections from experienced miners in infantry units.

Having started the war with only small Regular, Reserve and Territorial forces, in late 1914 and 1915, the British were in the process of forming a large New Army capable of taking on that of Germany. Thus, although the British Army began the war with a tiny number of engineers, lacking the specialist skills to carry out military mining, the fluid and civilianized nature of British voluntary recruiting meant that it was able rapidly to



German *Pioniere* connect a firing circuit for a mine charge, near Ban-de-Sapt, Vosges, May 1915. Mine warfare broke out in this sector in December 1914, culminating in the detonation of three German mines on 22 June 1915 that destroyed 50m of French front line. The two boxes contain a total of 200kg of *Sprengmunition* explosive (picric acid or TNT) and the use of a candle in close proximity suggests that the *Pioniere* had no electric or safety lamp. They are from the 2. Landwehr-Pionier-Kompagnie of the 2. Elsässisches Pionier-Regiment Nr. 19. (Brett Butterworth)



enlist specialist units, unlike Germany and France where the rigid process of conscription had already taken as many miners as could be safely borne by industry. In these circumstances, an energetic engineering contractor and Member of Parliament, John Norton-Griffiths, was able to play a key role in recruiting skilled miners and mining engineers, and also providing technical advice at the front. An acquaintance of the Minister for War, Lord Herbert Kitchener (himself a Royal Engineer), on 13 February 1915, Norton-Griffiths demonstrated to him a method used by his workers on a Manchester sewerage contract to dig rapidly through clay. Norton-Griffiths claimed that Kitchener asked for 10,000 such workers, though probably only a few hundred existed. Kitchener sent Norton-Griffiths to the front that evening to examine the ground and the first of his 'clay-kickers' were at work in the front line on 21 February (Norton-Griffiths 1915–16: 19–21 Feb 1915; Edmonds 1927: 32–33).

The British formed the new recruits into specialist tunnelling companies of the Royal Engineers, with the vast majority of the personnel being skilled coal miners. About half of the strength of the new units was obtained by directly enlisting miners from collieries, while the other half was found by transferring miners from units at the front. The colliery enlistments were often men who had already been rejected for service due to their age or injuries, and were sent to the front after just a few days' basic drill. Officers were recruited among mining engineers either already serving or by awarding temporary commissions, and were sent to France after a few weeks' training. For the next year, Norton-Griffiths acted as an advisor to General Headquarters (GHQ), visiting mining sectors at the front and obtaining personnel. By 1916, the number of tunnelling companies serving on the Western Front included 25 British, three Canadian, four Australian

ABOVE LEFT
Pictured near Fay, Somme, in 1915, this armed underground listener of Compagnie 14/3 of 4e Régiment du génie carries a French Simplex shotgun converted to a carbine to fire tear-gas or flare cartridges (see p. 10–11). His goggles were as likely to protect against the glare of chalk as against tear gas. (Collection La contemporaine LC_PH_ ALB_0010_07_08)

ABOVE RIGHT
Armed with a Luger pistol and stick hand grenade, *Pioniere* of the 1. Elsässisches Pionier-Bataillon Nr. 15 wait at a barricade in a mine gallery. The lack of timbering suggests a surprise break-in to a French gallery. The location is Bernhardstein, Vosges, about mid-1915. (Staatlichen Archive Bayerns)

and one New Zealand. Their impact was quickly felt at the front when they began to engage their German opponents beneath no man's land.

In 1915, charges quickly grew in size as German, French and British forces used mines during their attacks, to compensate for lack of artillery powerful enough to destroy enemy positions. On 3 February, the Germans fired four mines, each containing 5 tonnes of black powder and placed beneath the French positions by the Ruhrhessische Pionier-Bataillon Nr. 11, to capture three lines of French trenches in a rapid assault on the powerful Massiges position in Champagne (Hartenstein 1936: 128). The Germans, largely on the defensive in the West, were less likely to combine the firing of mines with set-piece attacks, although German troops gained a reputation for their ability rapidly to capture and consolidate mine craters, even when fired on by their enemies. When the Germans launched their main attack in the West, at Ypres on 22 April 1915, they relied on a combination of heavy artillery and chlorine gas to take Allied positions. The Germans mined actively wherever the front lines were closer than about 100m, however, primarily as an aggressive defence and also to gain local advantage.

A

UNDERGROUND FIGHTING

Contact between tunnels was a feature of underground warfare, even resulting in combat, and French and German pre-war manuals specified that if galleries were invaded they should be defended using daggers, hand bombs, firearms and noxious smoke or chemicals. Far more likely in soft ground, such activity also depended on the vigilance of listeners. Usually, enemy activity was detected and responded to with the detonation of camouflets before contact was made but, on occasion, timbers would be encountered or tunnels unexpectedly broken into.

In the soft ground of Flanders, the British and Germans experienced frequent encounters during 1915. Usually, they would place charges against the timbers and attempt to listen to gain intelligence about their opponents' intentions. On 6 September 1915, 173rd Tunnelling Company experienced two break-ins in a single day, when the floor of their tunnel gave way into a German gallery in which the enemy were lying in wait and opened fire. The British managed to escape and returned with explosives and sandbags to build a barricade and fire charges. In a different tunnel, 173rd Tunnelling Company reached German timbers where they placed and tamped a charge, using a length of armoured hose fixed against the timbers with which an intelligence officer listened for 19 days, but without gaining any information of value.

Later in the war, listening devices made such contact less common; but in many sectors, especially in hard ground, tunnels were so close that both sides were well aware of the proximity of the other, making contact a constant fear. At Vauquois in August 1917, when the Germans used a small camouflet to break into a French attack gallery, a *Vizefeldwebel* was able to enter and firing his pistol, dragged off a French sapper. The Germans then fired charges to cut off and capture a portion of the French galleries.

(1) Ypres encounter

This vignette is based upon an incident at the Bluff, south of Ypres, in November 1915, when 172nd Tunnelling Company discovered the timbers of a German gallery that was entered by two second lieutenants: Richard B. Brisco held back Germans while Arthur Hibbert fetched sandbags and explosives, and then the two men placed a 50lb charge against the German timbers. Both received the Military Cross for the incident. The German is a *Vizefeldwebel* of the 2. Westfälisches Pionier-Bataillon Nr. 24, armed with an M83 Reichsrevolver.

(2) French carbine and tear-gas cartridge

Tear-gas grenades and cartridges were developed by the French before 1914 and were intended for use in mine warfare. In the early part of the war, to compensate for a lack of flare carbines, French Simplex shotguns were re-bored to fire flare cartridges using the Chobert modification. The carbines were also capable of firing the 26mm 'cartouche suffocante', containing 35g of Chloroacetone tear gas. Such a weapon is recorded as having been carried underground by a miner on the Somme in 1915.

(3) French 'Couteau Boucher' fighting knife

This weapon is typical of the large quantity of butcher's knives acquired by the French Army in 1915.

(4) French grenade suffocante Modèle 1914

This grenade contained 200g of Chloroacetone tear gas.

(5) German Luger Pistole 08

(6) German Stielhandgranate 15

(7) British steel knuckleduster dagger

Made from a Pattern 1907 bayonet, this dagger bears the name of Staff Captain James A. Leeming RE, associating it with John Norton-Griffiths' general manager who received a temporary commission in 170th Tunnelling Company in March 1915 and who was appointed a staff captain attached to the Ministry of Munitions in June. Evidence of the use of such weapons by British tunnellers is rare, doubt having been cast on a drawing of a brass dagger believed to have been carried by the 2nd Canadian Tunnelling Company.

(8) British cut-down SMLE rifle

Weapons of this kind were used by underground listeners of the 2nd Australian Tunnelling Company at the Bluff in March 1917. It was recorded by the Assistant Inspector of Mines, Major Ralph S.G. Stokes, who regarded it as 'probably more dangerous than a revolver… rather like a Mauser pistol to handle' (Stokes 1916–17: 7 Mar 1917).

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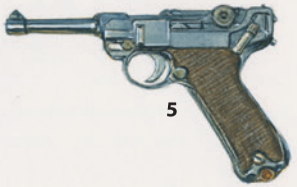

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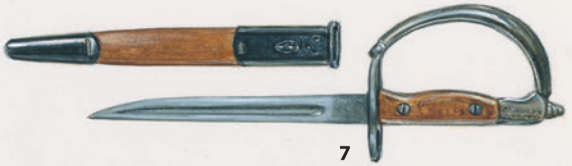

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Instructions issued by German *Pionier* (engineer) commanders in 1915 for the conduct and tactics of mine warfare were reiterations or re-printings of pre-war practice, even though developments at the front had already begun to render them obsolete (General of Pioneers 1916). Owing in part to larger numbers of specialized fortress pioneers, however, the Germans in many sectors were able to prevail over their French counterparts. The Germans also formed local units of infantry miners into *Stollenbaukompagnien* (infantry mining companies; converted into pioneer mining companies in 1917) on a divisional or regimental level, and in 1915 the Bavarian Army formed specialist pioneer mining companies, with the Prussian and other armies following suit in 1916.

On 3 March, the French General Staff issued instructions for mining to be used to attack important parts of the enemy front and reminded troops of the existing technical regulations. This included specifying the small size of tunnels traditionally used in mine warfare: the *demi-gallerie* (main workings) 1.3m to 1.5m high by 1.0m wide, but if the length exceeded 40m, then the *rameau* (branch), 0.8m by 0.65m, should be used (Service Historique 1931b: 433–34).

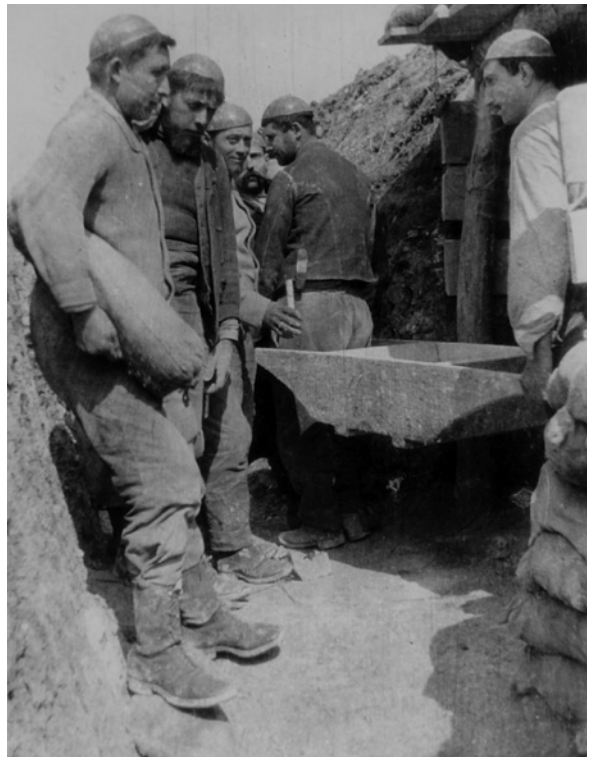
The French did not always fire mines at the moment of attack, but as with four mines at Les Éparges on 17 February, and 17 mines at Carency on 9 May, which employed 11.75 tonnes of explosives as part of the destructive phase during the preliminary bombardment. In both cases, the mines achieved a degree of success for the French; they took the western part of the Les Éparges ridge and the fortified village of Carency fell to them three days later. These French mining operations were carried out under the supervision of regular engineer officers, following practice laid down in the pre-war manuals. At Carency, Compagnies 20/11 and 14/5 adopted the practice of a classical mining system, including a transversal gallery parallel to their front line, to form a subterranean defence 20–30m out into no man's land (Thobie 1918: 151). In a feature learned during 1915, they also began deeper mine tunnels, 15–20m in depth, not from the front line but behind it, where they were less vulnerable to attack by mortars or raiding.

In two sectors, Les Éparges and Vauquois, ridges which afforded valuable observation, mining between the French and Germans escalated during 1915 and was to continue into 1918. By the summer of 1915, the summit of Les Éparges had ceased to exist, obliterated by craters up to 60m in diameter. In the

French engineer officer of Compagnie 14/3 of the 4e Régiment du génie tamping a mine charge, near Fay, Somme, February–August 1915. Tamping was the sandbagged backfill needed to prevent the force of an underground detonation being directed down the miners' own tunnel and was interspersed with air spaces and timber or even concrete reinforcement. Owing to the danger of tamping, in close proximity to the enemy and their own charge, officers would often tamp themselves or with trusted NCOs. (Collection La contemporaine LC_PH_ALB_0010_07_08)

autumn the rate of blows exceeded four per week, with a series of German detonations at the eastern end, culminating in four massive mines on 13 October in which an officer and 57 men of the French 303e Régiment d'infanterie disappeared. At Vauquois, between March 1915 and April 1918, French and German engineers fired 519 mines or camouflets along the ridge on a front less than 500m wide (Amis de Vauquois 2004: 289).

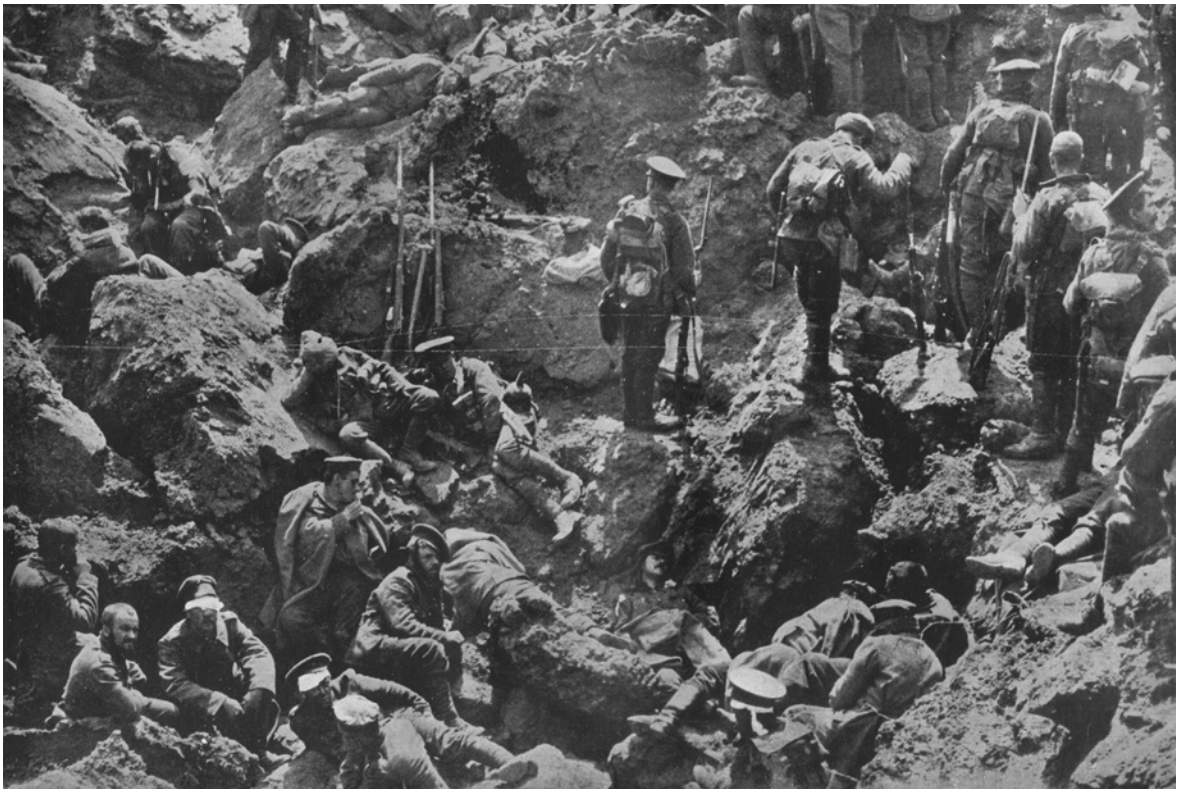
Even before the tunnelling companies became operational, British operations relied, at least in part, on expertise gained in civilian life. The first British mining success of the war was at Hill 60, a heap of spoil from a railway cutting, named from its height in metres, which gave the Germans clear observation over Ypres. Under the command of a Regular Royal Engineer officer, the work was carried out largely by miners serving with Territorial units of the 1st Northumberland Field Company, Royal Engineers, and the 1/1st and 1/3rd battalions, The Monmouthshire Regiment, joined latterly by the first men of the newly formed 171st Tunnelling Company. Five mines totalling 5,715kg successfully enabled the British to take the position, only for the Germans to retake it 19 days later using chlorine gas (Edmonds 1927: 168; Royal Engineers 1922b: 20–22).



A French fatigue party emerging from a mineshaft head, using a hand-barrow to remove mining spoil, near Fay, Somme, February–August 1915. Mining generated huge quantities of spoil, with around three men needed to support one man working at the face but, if allowed to accumulate, it gave intelligence to the enemy. It was an unpopular, hard and dangerous fatigue and, where possible, units engaged in mining obtained the attachment of dedicated carrying troops to ensure work was not delayed. The need to congregate around mine entrances especially attracted snipers, rifle grenades and mortars. These French carriers wear steel *cervelières* (skull-caps), issued by the French before the Adrian helmet. (Collection La contemporaine LC_PH_ALB_0010_07_08)

The tunnelling companies soon began to tackle the problem of sinking shafts through treacherous water-bearing sand, which had proved intractable to the military engineers in Flanders. The mining engineers understood that beneath the sand was water-impermeable clay that was the reason for the high-water level in Flanders, where trenches more than about 1m deep were liable to fill with water. Tunnelling in these wet sands required the skills of professionals using the techniques of sheet piling, or 'spiling', and steel tubbing 6ft (1.83m) in diameter, forced down very precisely by four 5-tonne jacks through the wet sand. If a shaft could be sunk through the sand into the dry clay, then tunnels could quickly be driven forward by the clay-kickers (War Office 1923: 137–42; Woodward 1920: 13–21).

The first mining operation solely carried out by the new tunnelling companies came on 9 May 1915, during the battle of Aubers Ridge, when 173rd Tunnelling Company fired two 2,000lb (907kg) mines it had laid in the blue clay. Unfortunately for the British, a severe shortage of artillery ammunition left them unable to exploit all of the mines that the tunnellers were able to place beneath German lines. At St Eloi, south of Ypres, on 10 July, 172nd Tunnelling Company fired mines of 1,400lb (635kg) and 1,500lb (680kg) and a series of smaller charges without attacking. On 19 July, however, the crater resulting from a 4,900lb (2,223kg) mine fired by 175th Tunnelling Company at Hooge, on the Menin Road east of Ypres, was seized by British infantry without a preliminary bombardment, only to be retaken by the Germans 11 days later using flame-throwers, in an echo of the loss of Hill 60.



The crater of one of two mines fired by 173rd Tunnelling Company beneath the German front line at zero hour at the opening of the battle of Aubers Ridge. This rare photograph, apparently taken on the day of the attack, shows German prisoners and British soldiers, probably of 2nd Battalion, The Lincolnshire Regiment. The mines assisted the attackers in advancing beyond the third German trench, though the British gains were later lost to German counter-attacks. (Print Collector/Getty Images)

Keen to harness the potential of the new tunnelling companies and hampered by a continuing shortage of artillery shells, the British continued using mines in attacks during the latter part of 1915. While the tunnelling companies gave the British a high degree of technical skill in driving underground, however, their expertise did not compensate for a lack of knowledge or experience in how to employ military mining. During an attack at Givenchy-lès-la-Bassée on 15 June 1915 a 3,030lb (1,374kg) charge, fired two minutes before zero hour, inflicted casualties on Canadian troops who were too far forward, while, with two minutes' warning, the Germans were able to get ready to repel the attack. On 25 September, when the BEF launched its largest attack of the war so far, the British fired nine mines: four at Ypres and one at Givenchy-lès-la-Bassée were part of diversionary operations; two further pairs, on the main attack front of the 2nd Infantry Division, in no way aided the British attack or had a detrimental effect. Unknown to the British, the Germans had withdrawn from their front line north and south of the La Bassée Canal owing to the success of British mining operations. This negated the effect of the mines at Givenchy-lès-la-Bassée and the northern pair on the 2nd Infantry Division front, which were fired at two minutes before zero hour. The southern pair were fired ten minutes before zero hour, putting the Germans thoroughly on the alert, and also forcing some of the attackers into a narrow causeway between the craters, where they were even more vulnerable to German fire (Edmonds 1928: 252–53).

At the end of 1915, both the French and the British commands were concerned that much mining effort had been wasted due to lack of coordination. For example, Général Charles Ebener, commanding 35^{e} Corps d'armée, complained of months-long struggles that might result merely in

the destruction of a German salient or trench, after which the attackers would then be faced by an intact second German line – a result that could have been obtained by a few hours' concentrated fire by heavy mortars and howitzers. On 17 December, Général Joffre told army group commanders that control of mining by subordinate units had resulted in a dilution of effort and only limited results. He stated that mining should be concentrated at carefully chosen points as a means of wearing down the enemy and called for reports on progress and the adequacy of equipment and personnel (Gorlet 2005: 160).

The British went further in control of mining operations in December 1915. To avoid the waste of mining effort on small, uncoordinated schemes, command of the tunnelling companies was moved from the divisional to the army level, with the appointment of Controllers of Mines to the three British armies on the Western Front. These posts were filled by Regular Royal Engineer officers who had previously commanded tunnelling companies, their places now taken by professional mining engineers. Mining would be coordinated at GHQ by an Inspector of Mines, on the staff of the Engineer-in-Chief. After higher-ranking officers turned down this post, early in 1916 the staff officer responsible for mining, Lieutenant-Colonel Harvey, took up this post. It had also been Harvey who, as Chief Instructor in Fortification immediately before the war, had raised the prospect of mining being necessary against entrenchments (Harvey 1929: 539).

Harvey appointed an experienced mining engineer to act as his assistant and as a liaison officer with the tunnelling companies across the expanding British sectors of the front. The formation of this command structure and the incorporation of extensive mining experience into the BEF rendered redundant the advisory role of Norton-Griffiths, who asked to be relieved of his duties in March 1916. Harvey, the son of a well-known Bristol sherry importer, recognized the distinct character of the tunnelling companies in terms of their civilian expertise. In contrast to the French and German engineer corps, he did not issue top-down technical instructions as to mining methods but ensured that experience and good practice were shared by circulating Mining Notes, allowing company commanders considerable leeway in their working methods (Inspector of Mines 1916–18).

On the Gallipoli peninsula, where British, French, Australian and New Zealand forces had landed in April 1915, the fighting became deadlocked and mining began in May. On the Anzac front of the Australian and New Zealand Army Corps, Ottoman forces initiated mining that became a major feature of the fighting on Second Ridge. Break-ins and underground fighting, but also a degree of 'live and let live', prevailed between the miners. Underground sapping operations to push the front lines forward into no man's land were also a major feature at the Anzac front.

The stalemate above ground increasingly drove offensive efforts underground. In September, the Corps commander, Lieutenant-General Sir William R. Birdwood ordered a comprehensive underground attack scheme, in which the mining attack plan by the 2nd Australian Division at Lone Pine was the most ambitious, with a low-level system at 18m depth, begun on 20 October. A yet deeper pair of tunnels was intended to convey infantry attackers to emerge behind the Ottoman lines (see p. 57). The reserves required to put these plans into action were not available, however, but had they taken place, the Australian Official Historian speculated that they might

Sapper Joseph Cox, 185th Tunnelling Company, wears working smock and waders at Albert, Somme, while working at La Boisselle during the winter of 1915/16. A miner, Cox enlisted from Warsop Main Colliery, Derbyshire, in October 1915. He died of wounds on 10 April 1917 during the battle of Arras, leaving a wife and four children. (Duncan Hunting)

have had an impact comparable to the mines at Messines Ridge in 1917 (Bean 1941: 820).

Mining at the British sector on the southern landing at Helles was begun by an VIII Corps mining company formed under Captain Henry W. Laws, a temporarily commissioned mining engineer in the Royal Naval Division. After Allied advances in June and July, mining resumed near the Vineyard and Fusilier Bluff, against local objectives with small charges in shallow tunnels, and numerous contacts with Ottoman miners in the soft ground (Grieve & Newman 1936: 77–84).

When the decision was taken by the British in November 1915 to evacuate the Gallipoli peninsula, a large number of mines were prepared to cover the withdrawal at Anzac Cove, with 14.7 tonnes of charges prepared and 11 tonnes fired, with a probably similar amount prepared at Helles. As on the Western Front during the same period, the proliferation of mines fired during the Gallipoli campaign from May 1915 until evacuation in January 1916 arose from intense but local struggles and were a symptom of the deadlock rather than the key to resolve it (Jones 2010: 85–92).

B MINING TOOLS AND METHODS

French and German pre-war mining tools continued to be used during the war. Military mining tools were typically smaller versions designed for the small size of mine galleries. An increase in the size of galleries during the war, in great part due to civilianization, also saw an increase in the size of tools used.

German tools

The German metal spade (**1**; *Sticheisen*) and clay pick (**2**; *Lettenhauen*) both appeared in the 1911 *Sprengvorschrift* (blasting regulations). A short-handled pick mattock (**3**) and short-handled *Pionier* spade (**4**) were also used.

French tools

These included a short-handled shovel (**5**), a mason's level (**6**) and 50cm, 1m and 1.5m mining bars (**7**).

British and Commonwealth tools

British, Canadian, Australian and New Zealand tunnellers seldom used pre-war military mining tools, instead favouring civilian designs, often adapted or specially constructed. Manufactured in 1903 by Richard Thomas Co. of Birmingham, this Australian-modified 4½lb (2.1kg) pickaxe (**8**) was used at Gallipoli in 1915. Cut down for use in a confined tunnel, this tool was recovered from Courtney's Post by the Australian War Records Section in 1919.

Push picks were used for quiet work, prising out lumps of clay or hard chalk and flint. They were the only pre-war mining tools used by the tunnellers, but still varied according to the ground and preferences between units. Examples illustrated here include an all-metal push pick (**9**) with a lever for extra force, used by 176th Tunnelling Company, as illustrated in Mining Note No. 10, March 1916 (Inspector of Mines 1916–18); a bayonet push pick (**10**), used to loosen lumps of hard blue clay and for silent working in chalk; and a push pick with spherical hand grip (**11**) for soft blue clay or sandy soil.

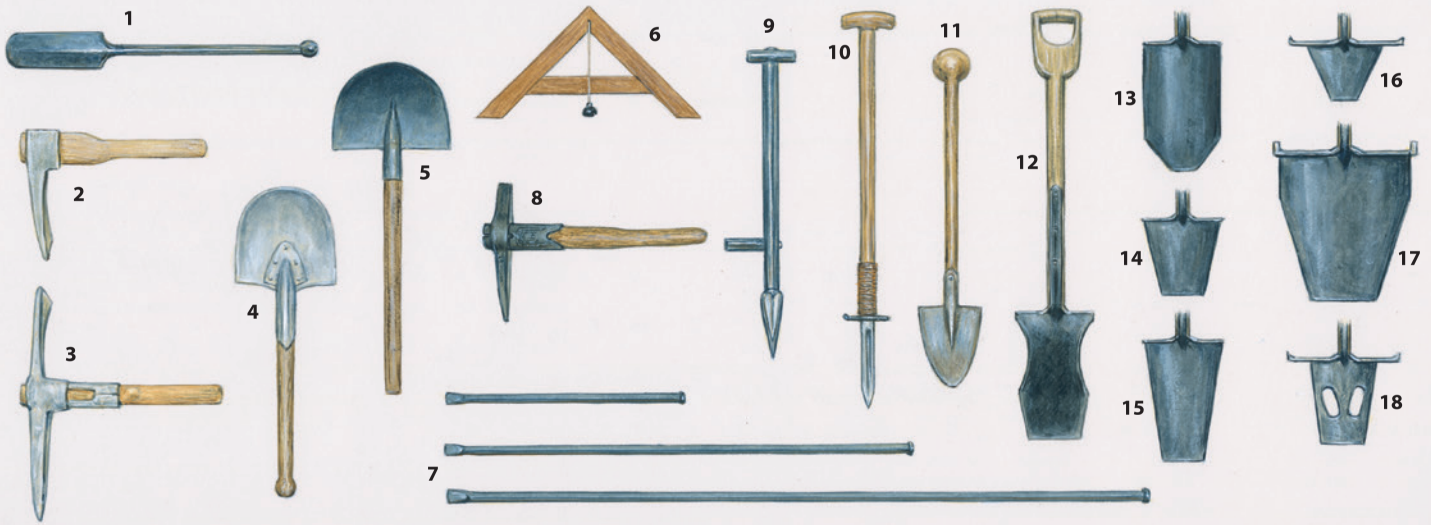
Clay kicking was a method of digging a tunnel through clay, used especially for excavating sewers beneath London and Manchester. The 'kicker' lay on a moveable small seat on a sloping board, using his legs to press a spade, known as a grafting tool, into the clay. Working from the bottom up, he would prise out spits of clay, which were cleared by men on either side. The technique had the advantages of excavating a low gallery at speed and in silence. The first clay-kickers, enlisted in February 1915, soon taught the technique to other members of the tunnelling companies, and in turn the Australians and Canadians.

Units each used their own grafting tools, with significant variations in design and size. Included here are those recorded at a clay-kicking competition between six companies near Ypres in October 1916. Unhindered by quiet working or listening pauses, the winning team advanced and timbered their tunnel 7ft 7in (2.31m) in four hours (Mining Note No. 66, Inspector of Mines 1916–18).

The 2nd Australian Tunnelling Company used a modified grafting tool (**12**), originally made by Caldwell of Stockton Heath and tapered with semicircular sections cut from the sides; it survives in the Museum of the Battle of Fromelles. Variants used by 171st Tunnelling Company (**13**; in use during March 1916), 171st and 1st Canadian Tunnelling companies (**14**), 3rd Canadian Tunnelling Company (**15**), 250th Tunnelling Company (**16**), 1st Australian Tunnelling Company (**17**) and 3rd Australian Tunnelling Company (**18**) are also depicted.

(19) 1st Australian Tunnelling Company in action, Ypres Salient, April 1917

Members of the 1st Australian Tunnelling Company are depicted clay kicking in Brisbane Gallery, Hill 60. This company attempted to place a mine 425m from their shaft beneath a German salient, northeast of Hill 60, in time for the Messines offensive. Despite driving the 27m-deep tunnel at a rate of 4.5–5.5m per day, reaching half of the distance in early May, the company abandoned the tunnel as it would not reach the objective in time. Shown here at the point when it passed under the British front line and the work was only semi-silent, spoil is shovelled rather than placed by hand in sandbags, and trucks are brought close to the face. The spoil trucks were fitted with solid-rubber tyres and ran on wooden rails to reduce noise, but could still be detected by listeners and so were not usually used within 30m of the enemy. Details are based on plans and descriptions by Captain Oliver H. Woodward (1920: 13–22).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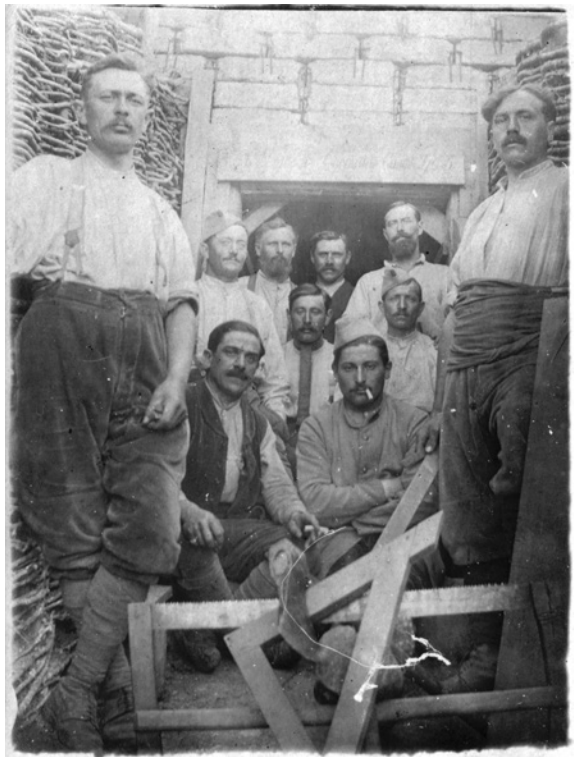
MINING IN 1916

The year 1916 saw mining reach its greatest extent on the Western Front. Although the French and Germans scaled back the use of mining as a means of breaking through the trenches during major offensive operations, some sectors reached a peak of activity. Meanwhile, the Germans had recognized the futility of the small surface operations that had initially accompanied their explosions: the struggle for possession of a crater was costly, bloody and random. French scepticism as to the value of mining also saw a major decline in its use in their sectors on the Western Front in 1916. In his course of instruction at the French military engineering school at Versailles, Lieutenant-colonel Pierre-Eliezer Lazard described (1932: 131–32) mine warfare by 1916 as combats that continued for their own sakes, without connection with the other arms, without prospect of marked success, for no other reason than that the two adversaries were entangled underground. The fight became a private one between the miners below ground. In British sectors, these fights remained particularly fierce with the tunnelling companies engaged in both active mining and planning for offensive operations.

Mining remained active where the Germans refused to allow the French access to observation, in particular the Argonne and the prominent ridges of Vauquois and Les Éparges (known to the Germans as the Combres-Höhe). The German launch of the Verdun offensive on 21 February 1916, approximately between the two ridges, saw mining activity increase in those sectors as the observation they afforded meant they were more contested. In the Argonne, there were 92 German and 131 French underground explosions between October 1915 and June 1916 (Lazard 1932: 129–30). Especially in the early half of 1916, the Germans achieved superior progress due to French shortages of personnel and equipment. The Germans were able to deploy more engineers, due to plans already in place to expand fortress battalions into regiments in time of war, and the formation of infantry mining companies drawn from experienced men at regimental and divisional level.

At Vauquois, on the face of it, the personnel was equal, with three French engineer companies facing the 1. Kompagnie, Pionier-Bataillon Nr. 30, and two *Stollenbaukompagnien*. German units had the advantage of remaining mining in the sector for longer periods of time whereas, in August 1916, three new French engineer companies relieved those that had by that time been at Vauquois for more than a year (Amis de Vauquois 2004: 252).

French shortcomings in mechanized equipment could not compensate for labour shortages until later in 1916, and lack of ventilation increased the time required to clear systems of gas after explosions. Compressed-air-powered drills were in particular used in the Argonne against the porous gaize sandstone that composed much of the geology of the region; more of these drills arrived from the middle of 1916, though the compressors were often also used for ventilation. Increases in personnel by the middle of 1916 allowed the French to launch a long mining attack at the Fille Morte. Early in 1916, the French cancelled a major mining attack at Les Éparges due to the shortage of specialist troops and equipment, and the distance between opposing lines. Following the German attack at Verdun, however, Général Robert G. Nivelle, commanding the II. Armée, ordered mining increased at Les Éparges, effectively in imitation of German organization. Countermines were to be sunk to a depth of at least 20m, begun as inclined galleries



from the rear slope; if the Germans were found to be deeper, the galleries would need to be started further down the rear slope. Nivelle also ordered systematic listening and reduced garrisons in threatened zones. The struggle continued throughout 1916, with charges fired of up to 40 tonnes (Service Historique 1933: 445–46).

Mining at Vauquois escalated substantially after the start of the Verdun battle. On 3 March, the Germans fired a 16.5-tonne mine placed 35m deep, making a 60m-wide crater. The explosion killed three French sappers who were lost underground while of 12 infantry missing on the surface, three were dug out alive six days later. The French managed to compensate for lack of personnel by using an electrical borer to fire a 5–6-tonne charge beneath the German front line on 23 March, destroying 60m in length and wiping out about 30 infantry.

The Germans were already waiting to fire a charge at the end of an 86m-long flanking gallery, involving an unprecedented 50 tonnes of explosives. The charging process had taken them 3½ weeks and employed 500 detonators with three separate sets of firing leads, sealed with tamping of 80m, including a 6m barrier of concrete. The Germans waited until 14 May to fire the charge, wiping out 108 French infantrymen and nine miners, destroying the French lines for 35m and leaving another 60m-wide crater. Yet the Germans made no attempt to seize the crater, appearing content for it to keep the French off the summit and to have destroyed their adversaries' efforts below ground. The French had to abandon planned retaliation with four mines totalling 100 tonnes when, even with the use of pneumatic drills, the 250 men required were not available.

The French High Command ordered that mining at Vauquois should be defensive while also acknowledging that energetic action was needed to

ABOVE LEFT
German miners in a typical close-timbered gallery, *c.*1915–16. Using a small miner's pick and an infantry entrenching tool, they wear drill overalls and sandbag caps. German close-timbering of galleries, regardless of whether the strata were self-supporting, was according to regulations and gave greater protection in the event of explosions, but it slowed work and used very large quantities of timber. (Author)

ABOVE RIGHT
French sappers at a well-constructed mine entrance, in June 1916. Carpenters' tools, including a mason's level, are visible in the foreground. (Author)

Among the most striking monuments of mine warfare, the village of Vauquois once stood on the summit of this ridge, now deeply riven by enormous craters. Bitterly contesting its observation across the Argonne and the Meuse River, French and German troops clung to either side of the crater lips, but the Germans kept the French from the summit. The steeper German rear slope on the right enabled them to employ horizontal tunnels that more easily drove beneath the summit. The French were disadvantaged by the longer slope to their side, necessitating longer and inclined attack tunnels. Reaching successively deeper beneath the summit, by March 1918, the Germans had driven to 95m, but both sides ceased mining the following month. (JEAN-CHRISTOPHE VERHAEGEN/AFP via Getty Images)

combat the deep German galleries started from their rear slope. The French were forced to combat these galleries using shafts from their front line until they could advance tunnels the greater distance from their own rear slope. Power plants for pneumatic picks and electric winches went some way to compensate for the French labour shortage. In September, the French began three new galleries intended to reach 38m depth but, due to errors by the engineer commander, reached only 20–30m.

At the end of 1916 there was no abatement in the intensity of mine warfare. When the French fired a 3.5-tonne camouflet in November, the Germans hit back the following month with one ten times the size. The French began to prepare a 22-tonne camouflet, half cheddite and half gunpowder, but on 31 December it detonated during charging, killing 36 men working in

C

MINERS' WORKING DRESS AND INSIGNIA

(1) German working dress and insignia

Dating from 1915–17, this Prussian *Pionier* wears the M1910 field cap and trousers, the jacket from the drill uniform and M1866 boots. He carries a CEAG standard electric safety lamp. The insignia displayed below him include sleeve badges for the 1. Bayerische Mineur-Kompagnie, 1915–18 (**2**), and the 8. Bayerische Mineur-Kompagnie, 1916–18 (**3**), and the shoulder strap for a soldier of the Sächsische Pionier Mineur-Kompagnie Nr. 333, 1916–18 (**4**).

(5) French working dress and insignia

Dating from 1916–17, this drill operator wears an M1915 Adrian helmet and a mixture of 1915 horizon-blue uniform and private clothing. He holds an Ingersoll-Rand 'Little David' pneumatic jackhammer drill. The insignia displayed beside him include the sleeve badge worn by sappers of the *chasseurs à pied* in 1914–15 (**6**), alongside those worn by corporals and privates of the infantry sappers (**7**) and NCOs of the infantry pioneers (**8**) during 1915–18.

(9) British working dress and insignia

Dating from 1915–16, this member of 185th Tunnelling Company in the Somme sector wears a Pattern 1914 Service Dress winter cap, without cap badge, having recently been transferred from an infantry battalion; an over-shirt of an unidentified pattern worn by tunnellers, which resembles a New Zealand Swanndri; and rubber trench waders. The insignia displayed next to him include the shoulder straps worn by officers, warrant officers and sergeants (**10**) and corporals and sappers (**11**) of 173rd Tunnelling Company, 1915–18; the shoulder straps worn by officers (**12**) and other ranks (**13**) of 254th Tunnelling Company, *c.*1916–18; the sleeve badges worn by various tunnelling companies during 1917–18, including British and 2nd Canadian (**14**), 1st Canadian (**15**), 3rd Canadian (**16**) and 3rd Australian (**17**); and the sleeve badge worn by the Australian Electrical and Mechanical Mining and Boring Company, 1917–18 (**18**).

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German *Pioniere* and infantry in a mine crater at Hooge, on the Menin Road east of Ypres, August 1916. They wear sandbag caps and one can be seen emerging from a mine entrance in the bottom of the crater. This is one of four craters blown on 6 June 1916, by the Pionier-Versuchs-Kompagnie of the Garde-Pionier-Bataillon, beneath the front line of the 28th Battalion (Northeast), Canadian Expeditionary Force, practically wiping out two companies. The Germans attacked and captured the craters in one of the few successful German mining attacks in the Ypres sector during 1916. The Prussian tunnels were at only 6–7m depth, not in the clay level, and the attack was possible due to a gap in the British tunnellers' defence. (Author)

the gallery. By year's end, the new German galleries were a full 10m below the level of the deepest French workings. The Germans also still had the advantage at Vauquois of superior equipment, personnel and mortars and could systematically put shaft entrances out of action (Amis de Vauquois 2004: 264).

Whereas the British began 1915 fighting to overcome German supremacy underground, their predominant objective during 1916 was to carry out mining attacks that could be coordinated with major offensives. By March 1916, the British sector of the Western Front was joined as a continuous front, encompassing Ypres and Flanders, Loos, Vimy Ridge, Arras and the northern Somme. In the sectors south of Ypres and Flanders, the mining was in chalk that had different characteristics in terms of the need for timbering, water levels, sound and listening. Like the French and Germans, the British made attempts not to fire mines unnecessarily but, by contrast, they continued to try to use mines at the opening of attacks for the shock destruction of the German front lines. The appointment of Controllers of Mines at army level and the Inspector of Mines on the General Staff had the specific aim of focusing effort onto major attacks. In the sector south of Ypres, from Hill 60 to Le Gheer, from late 1915 the tunnelling companies coordinated their work in preparation for a mining attack on the Messines Ridge and by June 1916 six large and deep mines were ready beneath the German lines. The requirements of coalition warfare, however, led to its postponement until the following year (see pp. 29–39), when the British participation in Joffre's attack on the Somme was made more urgent by the German pressure at Verdun.

Two British attacks in March 1916 demonstrated the growing power that the tunnelling companies could bring to bear on the destruction of the

German front lines. They also demonstrated the very thorough preparation required to capture the craters, and the even more difficult process of holding them.

At the Hohenzollern Redoubt, in the Loos sector, 170th Tunnelling Company charged four mines beneath or very close to the German lines just 9m below ground: one of 10,055lb (4,561kg), two of 7,000lb (3,175kg) and a fourth of 1,000lb (454kg). Even when mines were fired by their opponents, the Germans had developed a reputation for their ability to seize mine craters and the British made very careful preparations to ensure that their own forces would capture the craters successfully. Two British infantry battalions were allocated to the attack and, to maximize the shock value, rather than a methodical siege-warfare approach, there was no preliminary bombardment. The mines were fired at zero hour when the attackers were to rush from their trenches, with troops warned to avoid falling debris. The British attack was only partially successful, however, the mines forming craters 30–40m wide with their interiors a morass of liquid chalk and black mud. Fighting continued for more than a fortnight, during which the British were forced back to the crater lips nearest to their line (Jones 2010: 97–100).

The mines for the second operation, south of Ypres at St Eloi, were deeper, larger and technically far more significant than those at the Hohenzollern Redoubt. Having succeeded in sinking shafts to 20m depth through the wet sand into the dry Ypresian clay, 172nd Tunnelling Company had to charge six mines: one of 31,000lb (14,061kg), three of 12,000–15,000lb (5,443–6,804kg) and two smaller mines on the flanks. The mines would have been destined for the coordinated attack planned for the Messines Ridge, were it not for the capture at the Bluff of miners of 172nd Tunnelling Company who, it was feared, would give away the presence of the mines beneath the German lines.

The attack, scheduled for 27 March, was even more thoroughly prepared. Zero hour was at 0415hrs; two battalions attacking in darkness were to cross no man's land already obstructed by existing mine craters, warned to avoid the fall of debris from the detonating mines and had to negotiate gaps between the new craters to reach their objectives. Amid the transformed landscape, completely plastered with sticky clay and wet sand thrown up by the massive explosions, the attackers were unable to identify which craters they were supposed to be capturing. Rain hastened their filling with water, and the British only captured all of the four central craters on 3 April, six days after the attack. When the Canadian 2nd Division took over the sector on 4 April, it concluded that the position was untenable. A German attack on the night of 5/6 April succeeded in taking the four craters and German personnel set about skilfully draining and consolidating them into their front line (Jones 2010: 105–10).

A British aerial photograph of mine craters filling no man's land, April 1916. Mining came to dominate day-to-day trench warfare in many sectors of the Western Front, resulting in the opposing trenches facing one another across continuous lines of large craters. In 1916, the British fired 750 mines and camouflets, while the Germans detonated 696 against them. Less than 1,600m of front line is shown in this image of the Brickstacks and in front of Auchy-lez-La-Bassée. The German trenches at the top (east) of the photograph are recognizably deeper and more densely constructed. In this sector of Givenchy-lès-la-Bassée to Loos, mining activity on both sides reached a peak in June 1916, even though neither planned offensive action. Both sides' mining efforts were expended on diversions, attrition, clinging to local advantages and preserving the status quo. By 1917 there was underground stalemate and the British defensive transversal tunnels were enlarged into infantry communication subways. (Author)

The interior of one of the mines fired by the British at St Eloi on 27 March 1916, photographed during the following November when consolidated by the Germans. As well as being skilled at rushing and seizing craters, the Germans were also extremely effective at draining and fortifying them. This crater has the entrances to dugouts in the sides and mine tunnels in the bottom. (© IWM Q 42264)

Taken from an album belonging to Unteroffizier Heinrich Rehm, this photograph shows members of the 1. Reserve-Kompagnie, Württembergisches Pionier-Bataillon Nr. 13, in the La Boisselle mine system, *c.*1916. At 36m underground, they are well below the water level and several metres beneath the maximum depth reached by the British in this sector. Unlike their more numerous British adversaries, few if any of the Württemberg *Pioniere* were miners. The large quantity of heavy timbering far exceeds that used by British mining engineers in the very hard chalk, but protected against the many underground explosions. The pick seems too small to be of much use and progress at this depth was achieved with electric drills and shot blasting. The oxygen cylinder shown here was an ad hoc protection against carbon monoxide gas. (Wehrgeschichtliches Museum Rastatt)

The British reports into the loss of the St Eloi craters pointed to a number of factors, including the way that mines complicated an infantry advance that also had to be carefully coordinated with the phases of the artillery barrage. It was, however, established that the debris was less of a danger than perceived, having fallen within 15 seconds and within a 55m range, and mines could therefore be fired at zero hour to gain maximum benefit from the shock effect. In particular, the inability to hold the position once captured was taken very seriously at GHQ and was the subject of a special lecture to army commanders on 8 April. Aspects including the failure to dig communication trenches and strongpoints to facilitate consolidation, and the need for rapid defences on the crater lips were emphasized. GHQ issued the instructions in printed form and in May and June the British trained troops behind the lines in crater capture and consolidation by firing practice mines (General Staff 1916).

The Somme offensive, launched by the British Fourth Army after a week-long artillery bombardment on 1 July 1916, was on a far larger scale than any yet undertaken by the British. Five tunnelling companies were also to play a major role, firing 19 mines on the opening day beneath or close to the German front line, and preparing communication tunnels beneath no man's land (see pp. 56–60). Many factors were to mitigate the success of the Somme mines, however.

Despite GHQ's recent emphasis on careful preparation and consolidation in respect of mining attacks, these were largely disregarded when it came to planning for the Somme operations. The initial concept of the plan by the Fourth Army commander, General Rawlinson, had involved capturing only the first line of German trenches and consolidating them against counter-attacks. This, however, had been rejected by the British Commander-in-Chief, General Haig, in favour of a more ambitious attack encompassing much of the second line of defences in a single day. The highly effective German counter-attacks, encountered especially in mine-crater fighting, were to be swept aside by a rapid advance following an overwhelming weight of British artillery fire. Thus GHQ disregarded its own strictures following

FAR LEFT
Explored in 2012, this British transversal gallery was constructed during the winter of 1915/16 by 179th Tunnelling Company at La Boisselle, Somme. This underground defence ran parallel to the British front line, 24m beneath no man's land. From this tunnel, listening galleries were driven towards the Germans and could be enlarged to take explosive charges. The transversal gallery measures around 137cm by 84cm, and has wooden rails set into the floor for mine trucks. In contrast to the Germans, the British did not closely timber their galleries where the hard chalk was self-supporting, using just occasional props. As a result, the British could work much faster and required far less timber, but suffered higher casualties from collapses after underground explosions. (La Boisselle Study Group)

LEFT
An aerial view of Lochnagar mine crater with La Boisselle village behind. Begun by 185th Tunnelling Company, the mine tunnel was completed by 179th Tunnelling Company without detection to within 40m of the German front line. This was on the line of the road and was buried by the right-hand lip of the crater. When fired on 1 July 1916, however, neither the Lochnagar nor the Y Sap mine, on the far side of the village, was of significant benefit to the fatally flawed British attack. The Y Sap crater was filled in during the 1970s, but Lochnagar was preserved from destruction by Richard Dunning MBE in 1978 and is cared for by the Lochnagar Crater Foundation. (La Boisselle Study Group)

the St Eloi debacle, but neither Rawlinson, nor his chief-of-staff Major-General Archibald A. Montgomery, paid much attention to mines in the preparation. Even though Lieutenant-Colonel Frank Preedy, commanding 170th Tunnelling Company, was appointed Fourth Army Controller of Mines immediately after the Hohenzollern Redoubt attack, there is little evidence that heed was paid by the army staff to the lessons of the two key mining attacks in March. In particular, this may be seen in respect of the failure to fire mines at zero hour, as the British infantry rose to attack the German positions.

On 1 July, the British attacks in the south met with some success; in the centre there were partial gains for very heavy losses; but in the north only losses. The British artillery was incapable of destroying German defences to permit the deep advance upon which the attack depended. Although lack of heavy artillery is an explanation as to why the British continued to use mining attacks during their offensives, the destruction wrought by mines was too local – on too narrow a front and affecting the front line only – to have a meaningful impact on the success of the Somme attack. The result was that mines could do little to help, and even made it worse for the attackers. The British could not get mines beneath the most powerful German positions on the Somme as they were able to at Messines because of the extreme slowness of quiet work in chalk and the existence of extensive German mine systems. Whereas at Messines the British had got deeper than the Germans, on the Somme the Germans' more advanced use of electrical power enabled them to use pumps to get beneath the water level at around 30m depth. This meant that the British tunnellers were unable to place mines beneath powerful fortified villages, the taking of which was to prove extremely costly during the ensuing weeks of fighting. Existing mine crater fields on the Somme, over which it was judged impossible for the British to attack, only served to worsen the attackers' casualties due to enfilade from the flanks.

At Fricourt, 178th Tunnelling Company was unable to mine beneath the village, instead placing three mines of 9,000–25,000lb (4,082–11,340kg) in the existing mine crater field where they would bury the German front line. Fired two minutes before zero hour, the larger mine failed to detonate due to damp and the other two did little if anything to aid the efforts of

10th Battalion, The Prince of Wales's Own (West Yorkshire Regiment), which, suffering 710 casualties, lost more than any other British battalion attacking on 1 July 1916.

Near Mametz, 183rd Tunnelling Company used shallow tunnels to place a large number of charges beneath German positions. Of the two larger, one at Bulgar Point failed to detonate owing to a British mortar cutting the leads just before zero hour. The largest, 5,000lb (2,268kg) at Casino Point and fired at three minutes before zero hour, caused casualties to the attackers moving forward early but, like the other 183rd Tunnelling Company mines, also probably contributed to the success of the attack (Jones 2010: 114–15, 127–31).

At La Boisselle, Somme, German mine networks prevented 179th Tunnelling Company from getting under the key tactical point of the fortified village. Instead, the British drove 245m and 300m tunnels to place two large mines that aimed to screen German fire partially from two wide valleys into which British troops had to advance. The 60,000lb (27,216kg) Lochnagar mine buried the front line of a German position overlooking Sausage Valley, while the 40,000lb (18,144kg) Y Sap mine was beneath a position outlying the village defences overlooking Mash Valley. The Germans had evacuated the Y Sap just prior to the attack after hearing

D

LA BOISSELLE MINE SYSTEM, 1 JULY 1916

This drawing shows the mine system beneath no man's land on a 1km width of front at La Boisselle, Somme, during an 18-month period in 1914–16. It includes some 5km of tunnels and was constructed at between 4m and 30m depth by German, French and British engineers, during which they detonated more than 110 underground charges. German tunnels are shown in red, British in blue; German trenches are shown in pink and British in light blue.

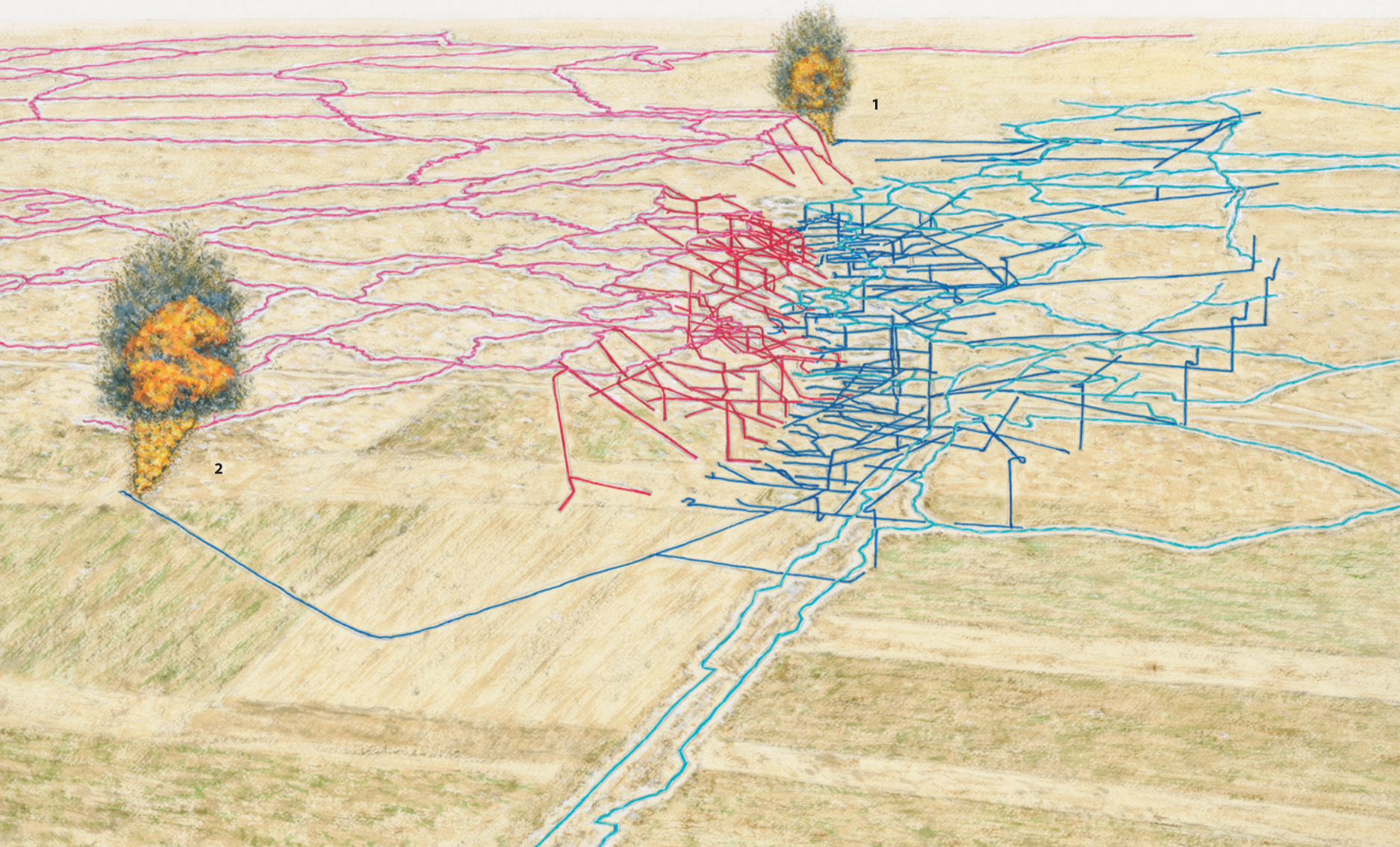
French engineers of the 11/4 Compagnie du génie began mining on Christmas Day 1914 to defend a farmstead on the village edge. Shortly afterwards, the 2. Bayerische Reserve-Pionier-Kompagnie also began mining and underground warfare soon escalated. From March 1915, the 1. Reserve-Kompagnie, Württembergisches Pionier-Bataillon Nr. 13, took over the sector, creating a defensive network based on a transversal tunnel situated 5–6m below no man's land, which provided a continuous listening gallery defending the front line. The Württembergers drove incline galleries down to 10–20m to drive beneath the French tunnels. The French used vertical shafts from their front line to 9–12m depth, making slow progress with cramped tunnels and did not connect their shafts laterally. By July 1915, the French were forced to abandon their front line and realized that the German tunnels were in places so deep beneath them, that they had no alternative but to try to destroy them by firing large charges from the bottoms of their shafts, destroying their own positions in the process.

When the French were relieved by the British 179th Tunnelling Company in August 1915, the Württembergers were in the process of creating a new deeper defensive system. The newly-formed 179th Tunnelling Company had to overcome a severely disadvantageous position based on untenable front-line shafts. When the Regular commander was replaced by a temporarily commissioned mining engineer, the speed of work increased and the British sank shafts to the 24m level to engage the Germans at an equal depth. On 22 November 1915, however, the Germans hit back with a massive 15-tonne charge that killed six miners and seven infantry.

During November 1915–March 1916, 185th Tunnelling Company was posted to the sector alongside 179th Tunnelling Company, and the British deployed 800–900 engineers and infantry labour – about twice the number of Germans – exclusively to mining in the sector. The British tunnellers created powerful defence systems at 24m depth and also to the water level at 30m, while the Württembergers extended their defence along the whole front and used electric pumps to reach below the water level. In February, 18 men of 185th Tunnelling Company, including the commander, Captain Thomas C. Richardson, were asphyxiated underground when methane gas exploded following a German camouflet.

While they were engaging the Germans beneath no man's land, the British were trying to find ways to launch underground attacks on the German trenches. The fortified village of La Boisselle was the key target, but the dense mine system was impossible to penetrate. In November 1915, 185th Tunnelling Company began an attack tunnel on the south-east flank known as Lochnagar, aimed at the German Schwaben Höhe position, 300m away. Having taken the position over, 179th Tunnelling Company managed to charge a mine without detection close to the German front line in time for the opening of the Somme offensive; it was detonated at 0728hrs on 1 July 1916 (**1**).

Using a 300m tunnel that aimed to bypass the German mining system, 179th Tunnelling Company drove a second mine on the north-west flank, beneath an outlying position known as the Y Sap. The distance was too great to cover using silent working in time for the opening of the attack, however, and the Germans detected the British and evacuated the position. The Y Sap mine was also detonated at 0728hrs on 1 July 1916 (**2**).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At 0720hrs on 1 July 1916, a 40,600lb (18,416kg) mine, placed without detection by 252nd Tunnelling Company, was detonated beneath the German Hawthorn Redoubt, near Beaumont-Hamel. The mine killed in the region of 30 Germans, but the explosion, ten minutes before zero hour, gave warning to the other defenders to emerge from their dugouts and open fire on the attackers as they began to cross no man's land. The detonation was photographed from about 500m away by Lieutenant Ernest Brooks and filmed by cameraman Lieutenant Geoffrey H. Malins. (CBW/Alamy Stock Photo)

179th Tunnelling Company at work, however, and neither mine significantly reduced the German fire across these valleys. The 6,380 casualties suffered by the British 34th Division attacking here were the highest of any British division that day. The northernmost mine, beneath the Hawthorn Redoubt, was mishandled by being fired a full ten minutes before zero and the northern attacks failed utterly. The British official historian, despite questioning all those who had planned the operation, was unable definitely to account for the reasoning behind the timing of the detonation (Jones 2010: 118–20).

After the failure of the British attempt to capture the German defences with a rapid attack, largely attritional fighting continued on the Somme until November, but few mines were used. The British made two attempts at High Wood in September, twice firing mines from the same gallery in which the crater was successfully held on the second attempt. The Hawthorn Mine tunnel was re-opened by 252nd Tunnelling Company and another charge laid, which was fired in a successful attack on 13 November. The mine detonation itself was now used as the zero-hour signal, with the attacking infantry already in no man's land, in front of their own wire, ready to rush the crater immediately (Jones 2010: 121–27, 131–32).

By the time the lesson had been learned, however, mining was even less relevant to the other emerging lessons of the Somme of how to coordinate infantry and artillery in taking and holding German positions. German defensive doctrine also changed as a result of the Somme, moving from a strongly defended front line to an in-depth defence. This potentially would lessen the power of mines in the attack, but they would continue to occupy their place in the British operational armoury into 1917.

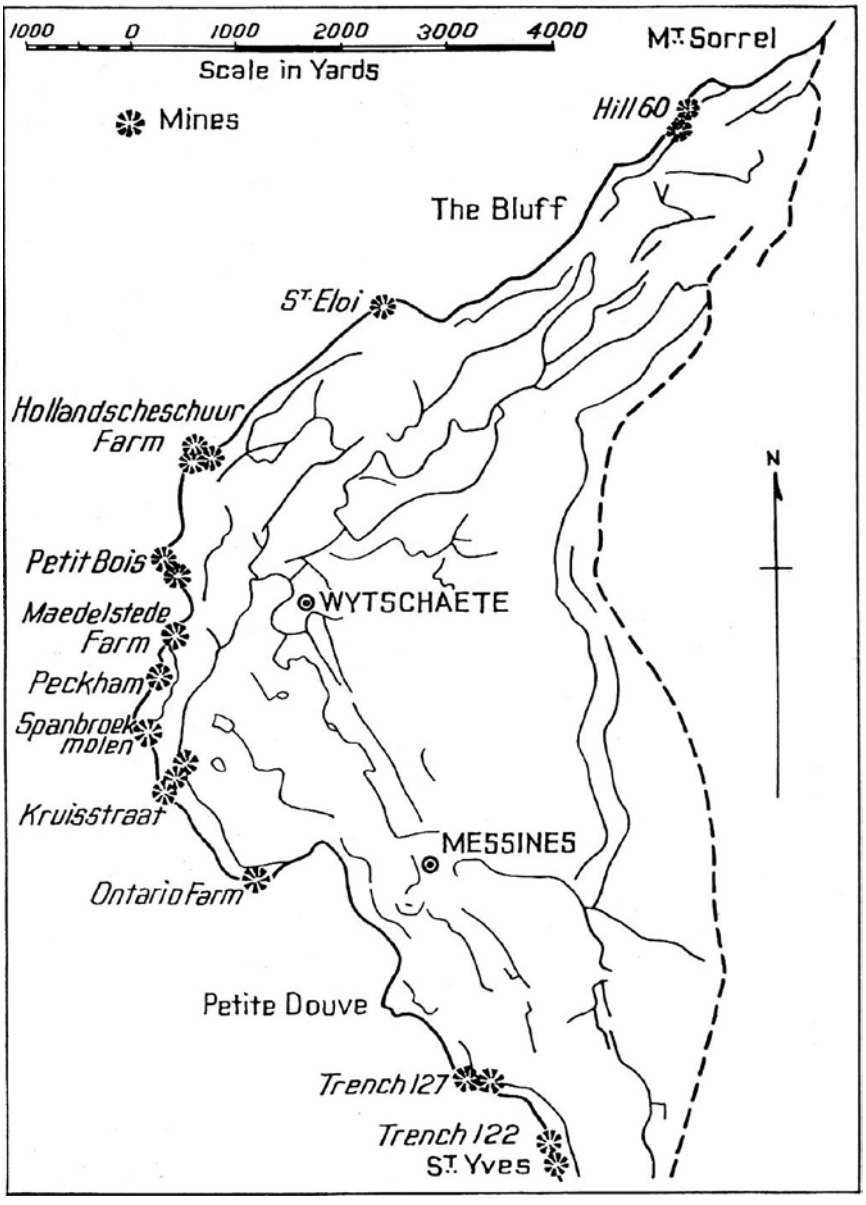
MINING IN 1917–18

In 1917, the effectiveness of the British and Commonwealth tunnelling companies saw the BEF continuing to use military mining when it had been superseded by new combined-arms attack methods. While the Germans and French had abandoned mining, and were trying to disengage from attritional mine warfare altogether, the British remained committed to it as an offensive weapon. This was not to survive beyond the middle of 1917, however, and the Vimy Ridge and Arras battles, launched on 9 April 1917 and the first fought using revised British tactical methods resulting from the Somme offensive, saw a partial rejection of mine warfare by commanders. Tunnelling companies on Vimy Ridge successfully placed 11 mines beneath the German front line in preparation for the attack by the Canadian Corps. The experience of Canadian commanders in mine warfare on the Somme and at St Eloi did not dispose them towards their use, however, and only three were actually fired; in particular Major-General Arthur W. Currie, commanding 1st Canadian Division, vetoed the use of mines owing to the hindrance they would cause to his advancing troops. The Canadian Corps also determined that the attackers should infiltrate across the mine crater fields to prevent dangerous enfilade fire, rather than avoid them as at the opening of the Somme attack. The successful capture of Vimy Ridge was a vindication of the decision, although Lieutenant-Colonel Guy C. Williams, the First Army Controller of Mines, pointed out that firing a charge at Broadmarsh would have dealt with German machine-gunners who had held up the attack. Only one mine was fired at the launch of the battle of Arras, owing to the withdrawal of the Germans to the south just prior to the attack. This mine was reported to have destroyed German defences, but also adversely affected the attackers (Jones 2010).

The detonation of 19 mines at the opening of the battle of Messines on 7 June 1917 is rightly seen as the crowning achievement of the British, Canadian and Australian tunnelling companies. It was the culmination of an 18-month-long struggle of bravery, endurance and technical skill underground between British and German miners, and a victory of patience and commitment by the British command. But by the time the Messines mines were fired, warfare had changed and overemphasis of the significance of the mines in the loss of the ridge became a useful scapegoat for the Germans.

The mines fired at St Eloi on 27 March 1916, while a failed operation from the British perspective, had a disturbing effect on the German *Pionier* service. The operation brought the realization that the British had the technical ability to sink through the sand and attack using the clay to stage surprise mining attacks on the German positions in Flanders. As a result, the Germans took a series of measures. First, a *Pionier* regiment commander, Oberstleutnant Otto Füsslein, was brought from Les Éparges to take over mining in the Wytschaete (Messines) sector. Second, the Germans issued a revised instructional pamphlet on mine warfare (Kriegsministerium 1916). Third, they began creating specialized *Pioniere-Mineur-Kompagnien*, following the lead of Bavaria, but also in imitation of the British tunnelling companies. These specialized companies were formed from existing infantry mining detachments and included many miners in their ranks.

Füsslein warned that the British could surprise them again. Instructions issued in June by the *Kommandeur Pioniere*, XXIII. Reservekorps (1916),



Published after the war (Harvey 1931: 516), this map depicts the 19 mines fired at 0310hrs on 7 June 1917 at the outset of the battle of Messines. The German lines are indicated with dashes showing the line reached by British and Commonwealth forces on 14 June 1917. The ability to work quietly through clay meant that the tunnelling companies could place large charges beneath all of the key salients in the German lines on the attack front. Only at La Petite Douve did German counter-mining render a British charge unusable. (Reprinted with permission of the Society of American Military Engineers)

show the Germans upping their game, departing from simply reiterating pre-war regulations, to include the location of deep shafts behind the front line, an understanding of the Flanders geology, the use of deep 25m defensive transversal galleries, and even the use of civilian titles for the personnel controlling mine workings. Although in September Füsslein was promoted to command all of the miners on the Flanders front in the 4. Armee, he struggled to put these instructions into practice, handicapped, he was later to complain, by restrictions at the command level, in personnel and equipment. Moreover, by June 1916, the Germans were in places too late, as the British had already laid seven mines beneath their lines on Messines Ridge and, with the postponement of their attack, were preparing more.

The effort required to lay, maintain and keep secret the mine charges for in some cases more than a year, is testament to the resources which the

British command was willing to devote to mining. As at the Somme, about twice as many British as German personnel were committed to mining. The British were also far more willing to divert expert personnel to mining in preference to other areas of the war effort. Whereas by the end of 1915, almost all British tunnelling companies were commanded by mining engineers, according to Füsslein (1931: 541), the German *Pionier* service prevented the appointment of such individuals to command specialist mining companies. Likewise, the limited availability of geological expertise, of which there was no shortage in Germany, also handicapped German mining ability. Until May 1916, when Prof. Dr. Passarge was assigned by the 4. Armee to advise on mining, the German *Pionier* service lacked the understanding of geology in Flanders to enable deep mining. Especially given the lack of mining engineers in *Pionier* units, the availability of geologists to the *Pionier* service remained a weakness (Willig 2023: 168–71). On the British side, mining engineers were augmented by civilian experts at GHQ. Lieutenant William B.R. King, formerly of the British Geological Survey and a Territorial Force officer with the Royal Welch Fusiliers, was attached to GHQ from June 1915. Moreover, among the valuable technical experts who arrived on the Western Front with the Australian Mining Corps in May 1916 was Tannatt W. Edgeworth David, Professor of Geology at the University of Sydney.

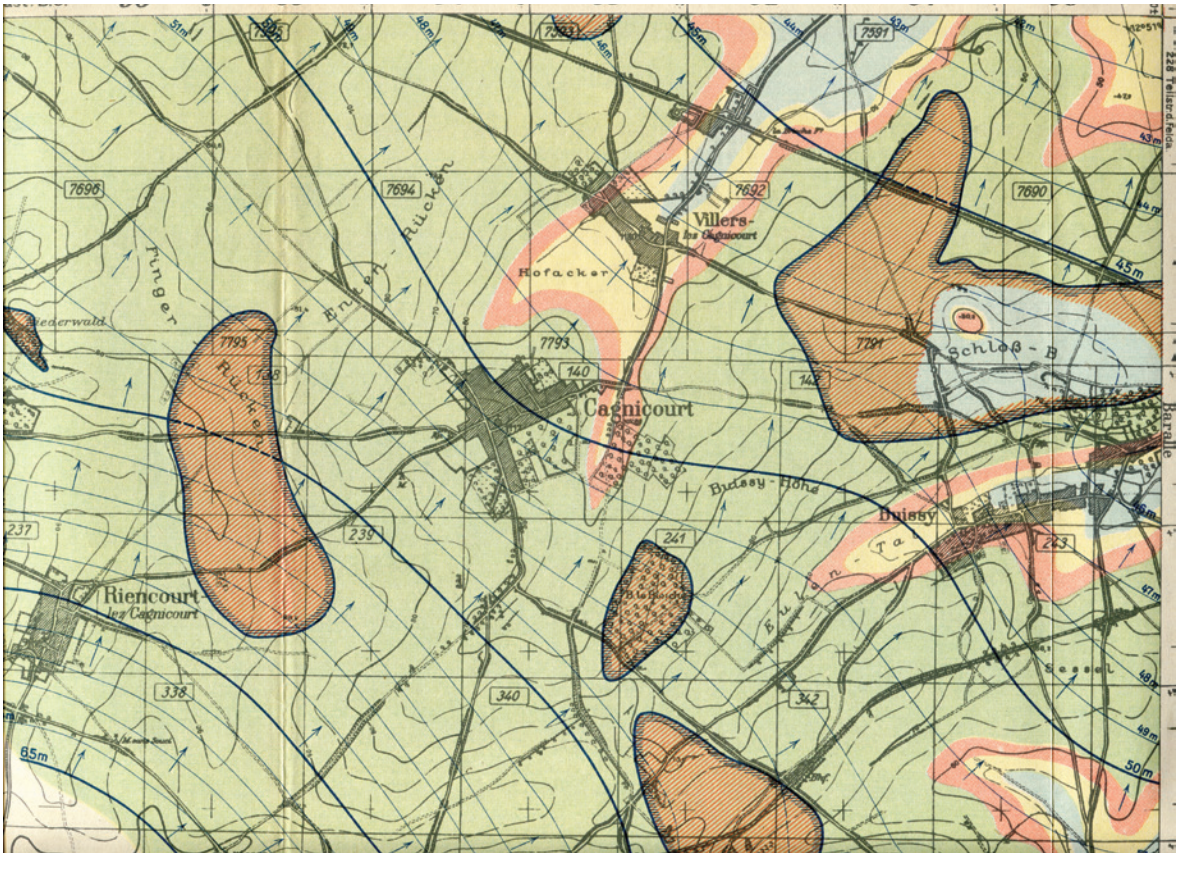
The idea of using the Ypresian clay to tunnel beneath Messines Ridge, often ascribed to John Norton-Griffiths, was probably first conceived by a New South Wales mining engineer named Cecil H. Cropper who commanded 250th Tunnelling Company. Realizing that he could use the impermeable clay that lay beneath the wet sands to attack the German positions, in December 1915, Cropper proposed driving long and deep tunnels to reach a series of German strongpoints. The scheme approved by Second Army was the origin of the Messines plan that was taken up and championed by Norton-Griffiths. (© IWM HU 120616)

The skills and technology for sinking the shafts proved to be the keys to the Messines mines. Unrestricted by the military mining orthodoxy that required tunnels to be as shallow and short as possible, tunnelling company commanders such as Cecil H. Cropper advocated locating shafts in dead ground behind the front line, away from observation, where the necessary plant for power supply could be organized. Once at the dry level, clay-kickers dug rapidly and quietly towards the German lines. Predicting the interface between the wet sand and dry clay was especially hazardous where the tunnel was run through the upper level of the clay–sand mix (Paniselien or 'bastard' clay). This was the case at Peckham where, after 250th Tunnelling Company had successfully laid a charge of 87,000lb (39,463kg) at 21m depth in April 1916, a branch for a second charge suddenly gave way with an inrush of sand and water, almost burying the men at the face. Recovering the tunnel after this and a second collapse, 250th Tunnelling Company laid a second smaller charge, only for the ground to give way again, cutting off both charges. The tunnellers then had to re-dig the tunnel through good ground for almost 300m until finally reconnecting the firing leads for the larger charge in March 1917, but were forced to abandon the smaller charge.

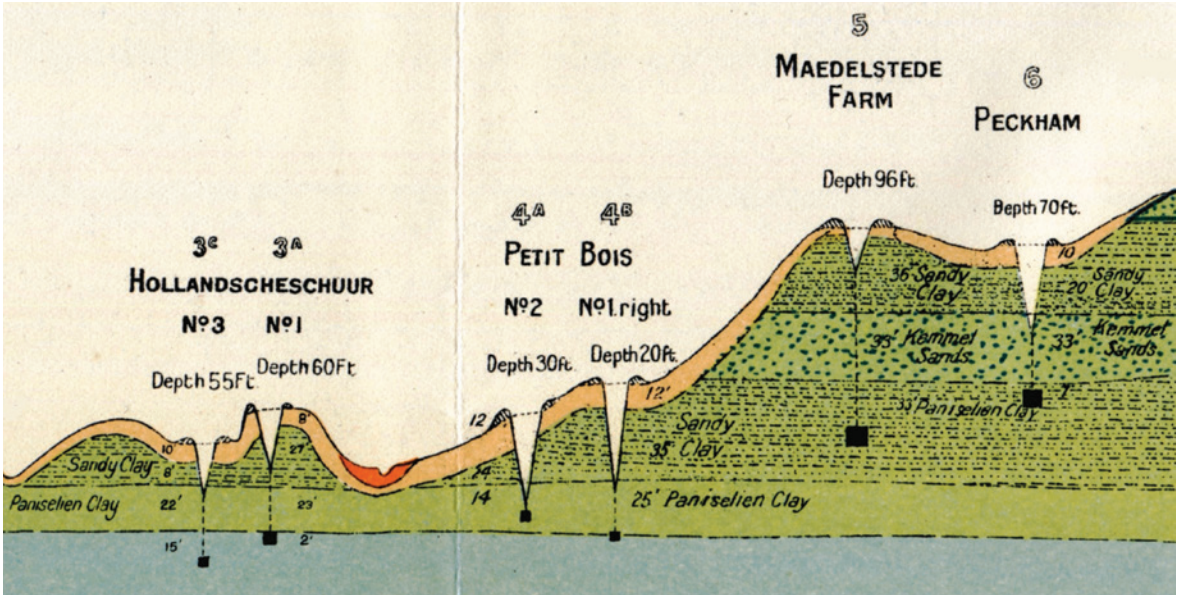
The need to conceal the existence of the deep attack tunnels from the Germans required elaborate deception. Deliberate noise from more shallow workings masked the presence of the deep tunnels, a technique used especially at Hill 60. After the 3rd Canadian Tunnelling Company laid a charge 27m beneath Hill 60 in August 1916, it constructed above it a mine system at 15m depth. This had the dual functions of detecting any German

presence that might endanger the charge, and creating false noise to disguise the Canadians' own activity in the deep system, including a branch tunnel to attack the Caterpillar position. The Germans would be given a false sense of security if they believed that their opponents were working only at the 15m level. When the 1st Australian Tunnelling Company relieved the Canadians in November 1916, it continued the deception while keeping the two charges viable until firing. The long interval between many of the charges being laid and the actual attack gave the Germans a false sense of security. Füsslein did not realize how far the British had been able to protect their charges against long-term immersion in water.

The Germans did not grasp the extent of the British mining attack and Füsslein would later describe how his miners were hampered by a series of difficulties (Füsslein 1931: 541–48). This should not, however, detract from the fact that the *Pioniere* were active and vigorous opponents. From June 1916, Füsslein began new shafts at locations 100–300m behind the front line, which he was gradually able to extend along the whole sector; but these shafts, sunk with tremendous difficulty 20m into the wet sand, failed to reach the dry clay, while firing from them was an emergency measure that usually destroyed the shaft. Füsslein lamented the fact that tactical control of mining remained with divisions, making it difficult to abandon the practice of sinking shafts from the front line, as the divisions wanted to retain these for defensive purposes. Divisional commanders failed to grasp that the British had gained a year's head start over the German miners. The Ypresian clay turned a distinctive blue on exposure to the air, and the



German groundwater and mining map, south of Arras, 6. Armee, November 1917. Geological maps indicated depth of groundwater for dugout construction and mining, seasonal fluctuation and direction of flow. (Author)



Published shortly after the war (Royal Engineers 1922b: Fig. 10), this illustration shows geological profiles of six of the Messines mines. A detailed understanding of the geology was vital for locating and identifying the clay and clay–sand mixes that could support the attack tunnels. Nine mines were laid in the true deep Ypresian clay (shown as blue), four were laid in an overlying dry clay–sand mix, while the remainder were laid in an upper moist sandy clay level. (Public Domain)

appearance of this spoil on the surface at different points along the ridge was ominous, even though care was usually taken to conceal it. At Ontario Farm, Füsslein was suspicious when water drained too quickly from one of his mine craters, suggesting a British tunnel was below, but the divisional commander prevented him from firing a heavy mine because the division's own concrete defences in the front line would be destroyed (Füsslein 1931: 544–45).

Nevertheless, the Germans were able to cause damage and delay to the British at Messines. Camouflets in May 1916 impeded progress at Hollandscheschuur, and in early 1917 at Maedelstede Farm, where the charge was only ready one day before the attack. At Spanbroekmolen,

The Caterpillar Crater, the result of 70,000lb (31,751kg) of ammonal explosives detonated 30m beneath the German position. Two mines were originally charged in October 1916 by the 3rd Canadian Tunnelling Company using a branch tunnel from the Hill 60 mine, but access was lost to both mines due to flooding. The explosives remained dry in waterproof tins, however, with the detonators sealed in bottles and three sets of detonator leads protected by armoured hose. The 1st Australian Tunnelling Company successfully fired the Hill 60 and Caterpillar mines on 7 June 1917. (Author)

Pioniere attempt to dig a wet timber-lined shaft in Flanders, 1915–17. Relying on timber- or concrete-lined shafts, the Germans struggled to sink through the wet sands of Flanders to reach the dry clay. They were handicapped by a lack of specialist expertise and equipment in field *Pionier* companies, while the success of British mining engineers with cylindrical steel tubbing was the key to the Messines mines. (© IWM Q 61047)

in February 1917, one smashed a branch gallery that the British had to abandon for fear of attracting more attention. Another German charge in March destroyed the main British gallery and it took 171st Tunnelling Company three months to bypass the damage and reconnect with their charge, achieved within just a few hours of zero hour. The same month, the Germans managed to damage and flood one of four charges at Kruisstraat with a camouflet that caused flames to shoot out of the British mineshaft head. Despite this definite proof that his men had located a British tunnel,

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FIRING THE MINES AT MESSINES

Lieutenant Bernard C. Hall and Sergeant Leonard T. Beer, 3rd Canadian Tunnelling Company, fire the Ultimo and Factory Farm mines, 0310hrs, 7 June 1917. Both men wear standard service dress and Sam Browne or Pattern 1908 web equipment. The lower scene shows Westminster Avenue communication trench, off Trench 122, deserted, as the attacking infantry had been sent back from the front line owing to the danger of injury from the shock waves from the mines about 245m away. These mines, of 20,000lb (9,072kg) and 40,000lb (18,144kg), were the two southernmost of the attack and had been in place for a year.

Hall and Beer had received their orders at 1600hrs on 6 June to fire the two mines at 0310hrs the following morning. They first had to lengthen 12 sets of firing leads, each mine having six duplicate sets in case of damage, from the bottom of the shaft to fire instead from the top, owing to fears that the shaft would collapse. They then had to carry out a resistance test of the circuits. On the trench is a Box, Testing and Jointing, used for testing electrical firing circuits, which contained a battery, a Wheatstone bridge, and a galvanometer. Hall records that he used a Wheatstone bridge and a 120-volt battery to test the circuits after lengthening them. The work of extending and testing the circuits took more than ten hours; during this time incessant German gas shelling necessitated the wearing of small box respirators continuously to the point where the facepieces were wearing out. Hall and Beer completed the lengthening of the circuits with 20 minutes to spare.

The current to detonate the charges was created using Mark V Dynamo Electric Exploders: here, Beer has a single one and Hall has two coupled together. Hall was provided with a watch, which he could see only with difficulty through the misted eyepieces of the respirator. He was told that there was a correction to the watch, and that he was to wait 13 seconds after 0310hrs before firing. He was too busy to be scared, but conscious that it was a big moment. In the seconds before firing, both men pumped the plungers of the exploders several times before slamming them down.

The shock wave threw both men 20ft down the trench, Beer still pumping on his exploder. They saw nothing of the explosion, but heard debris falling and concrete bunkers hitting the ground. The shaft was completely filled in with running sand (Hall 1960). Beer's medical records show that after June 1917 he suffered from shock and exposure, what might now be termed post-traumatic stress disorder.

The lower scene of the two mines exploding depicts the instant several seconds after the upper scene. Eyewitnesses described seeing enormous volumes of scarlet flame that illuminated the countryside. Although the shock waves were felt powerfully, the detonations deep underground did not create loud bangs; what was heard was the firing of more than 2,000 British guns opening fire simultaneously.

Füsslein had destroyed his shaft in firing the charge and so was unable to follow up the attack, enabling the British to repair the damage (Grieve & Newman 1936: 230–31).

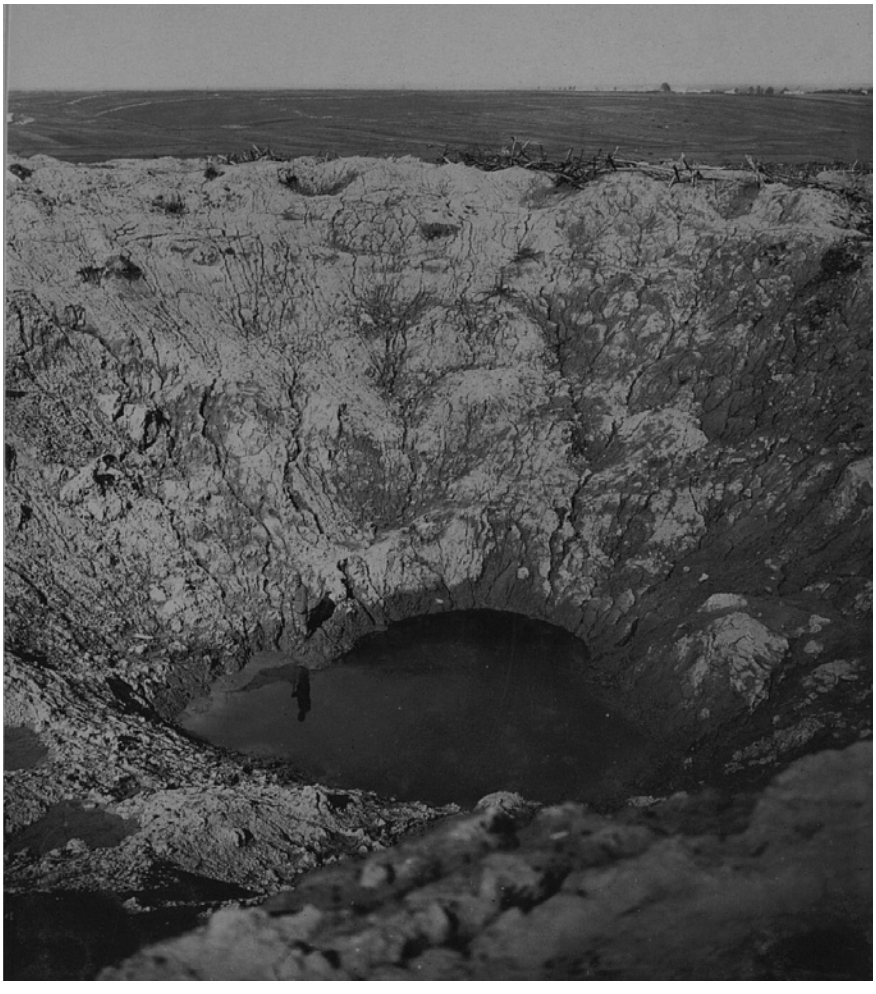
The dilemma which the British faced was that if they defended their tunnels when threatened by the approach of the Germans, it only served to alert the enemy of their presence. This was the case at La Petite Douve Farm, where Füsslein's counter-measures achieved their sole success. In July 1916, after placing a 50,000lb (22,680kg) charge beneath a German salient, 171st Tunnelling Company had begun a branch for a second mine. In August, with great difficulty, the Germans sank two timber-lined shafts, one reaching so close to the British tunnel that they thought the Germans were about to break in. The British laid a small charge in the branch, designed to rupture the clay and flood the German workings but not detonate their main charge. British geophone listeners could hear the Germans talking and, when they broke into the tamping of the smaller charge, the British fired it, killing an officer and eight men. When, a few days later, the Germans fired another camouflet, killing several miners and destroying about 120m of gallery, the British had no choice but to abandon the main charge, which lies to this day beneath the rebuilt farm (Grieve & Newman 1936: 232–35; Barrie 1962: 243–44).

The largest loss of life inflicted on the British tunnellers during the German attempts to stop the Messines mines also saw a remarkable feat of endurance by a miner. At Petit Bois, the British tunnel had already passed beneath the German front line when, in June 1916, German charges collapsed a 75m length, cutting off 12 men at the face. Rescuers bypassed the destroyed portion in a record 6½ days, but found it filled only with bodies. On returning later in the day, they were greeted by a living miner, 36-year-old Sapper William H. Bedson, with the words: 'For God's sake give me a drink! It's been a damned long shift!' Alone among the 12, his pre-war experience of entombment during a colliery accident had enabled him to survive the ordeal (Grieve & Newman 1936: 217–18).

On 24 May, Füsslein reported that the danger of mine attack on the ridge had been averted by his counter-measures, but the army group chief-of-staff, Generalleutnant Hermann Josef von Kuhl, later regretted not having ordered the evacuation of the ridge as it would have spared the German Army 'one of the worst tragedies of the world war' (Oberkommando des Heeres 1939: 475). The British Second Army took and held the Messines Ridge in what was regarded as one of the most successful limited-objective operations of the war.

The impact of firing the Messines mines has become the stuff of legend. The shock wave of the mines was mistaken for an earthquake in Lille 19km

The view from the bottom of one of the enormous craters of the Messines mines four days after the battle; figures can be seen on the rim. The detonations caused obliteration to the German front lines of up to 130m in diameter, but the enormous craters were obstacles the attackers had to negotiate. (Daily Mirror/Mirrorpix/ Mirrorpix via Getty Images)



A German mine crater at Mogilahöhe (Mogila Hill), Eastern Galicia (Ukraine), 1917. Although mining was less intense on the Eastern than the Western Front, it nevertheless took place at some 50 locations. This crater was the result of a mine in the surface loess layer of this bitterly contested 394m summit. (Danvis Collection/ Alamy Stock Photo)

away, but the sound heard by the Prime Minister, David Lloyd George (who was at his home in Surrey, not in Downing Street), was the firing of more than 2,000 guns, not the mines. The detonation of the mines caused panic in the German lines and destroyed a number of key concrete German machine-gun positions that otherwise could have held up the attack by causing heavy casualties. A figure of 10,000 Germans, often erroneously stated as killed by the mines, is in reality the number of missing from the whole battle. If the number of prisoners is deducted, the figure is 2,800 killed, the majority of whom died as a result of highly effective British artillery fire (Jones 2017).

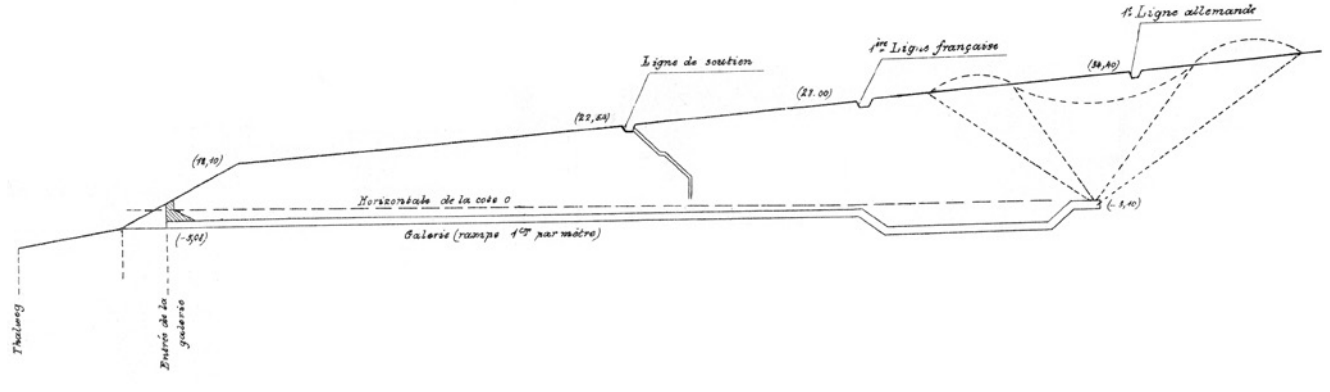
Although the Germans had not withdrawn from the ridge, in line with a shift to defence in depth, they were holding their front line with far fewer men. Major Ralph S.G. Stokes, the Assistant Inspector of Mines, who examined three of the craters on the day of the attack, concluded that the mines had killed 10–20 men each, making the total number for all 19 mines about 380 (Stokes 1916–17: 7–8 Aug 1917). The reality is that both offensive and defensive tactics had changed to make mining of less value. The Germans no longer relied on a powerful front trench to be held at all costs, but on a thinly held outpost line that would delay the attackers, who would be forced to undertake a long advance through defensive artillery fire until

they reached the main defence line. The British attacks, using deep advances behind barrages, were also designed to overcome these new German tactics. Mining, with its focus on breaking through the front line only, had been left behind by these changes.

By January 1917, French command policy reduced mining activity where possible, and had ceased to base attacks around mine detonations. Only in the most active sectors, such as Les Éparges, parts of the Argonne and Vauquois, was it impossible completely to eradicate. At Les Éparges, although the French still clung tenaciously to their side of the ridge, the German galleries reached into the rear of the French position. From the autumn of 1917, the firing of mines became less frequent, but continued into the following year, with one fired as late as August 1918. When the ridge was captured by Allied forces during the battle of Saint-Mihiel on 12–13 September, however, mining played no part.

In the Argonne as a whole, by the end of 1917 mining was active only at Cote 285 and at Fille Morte, where the French had fired their largest mine of the war with the Mine Z mining attack. The latter had originally been conceived in mid-1916, using two 60-tonne charges fired as part of a full-scale infantry attack with the aim of destroying German strongpoints and seizing high ground. By the time Mine Z was fired in May 1917, however, the French made no attempt to attack. As with the German 50-tonne mine at Vauquois, it served purely as part of the underground war. Mine warfare in the Argonne finally died down by spring 1918. Colonel Lazard (1932: 149–50), while acknowledging the energy, skill and valour of the engineers, commented that, as a whole, mine warfare did not modify in any significant way the general situation of the Argonne sector.

Mining proved hardest to eradicate at Vauquois. In early 1917, French efforts to hit back at the Germans only met with further evidence of major deep workings. In March, the French explored how to destroy completely the German positions and withdraw from the ridge. Charges of up to 280 tonnes at 50m depth were considered but complete destruction judged impossible, and the Germans would still be able to occupy the craters. The workings were so deep that few firings broke the surface, with the result that gas was trapped in cavities formed in the sandstone. New French galleries, driven from their rear slope, came into service by June, but the pace was slackening and the Germans fired their last mine charge on 19 March.



The profile of the Mine Z attack tunnel is depicted in this drawing, published after the war (Lazard 1932: Pl. XII). In the Fille Morte sector of the Argonne, a 50-tonne charge, the largest French mine of the war, was planted beneath the German lines using a 253m-long attack tunnel. By starting from a point 190m behind their front line, the French were able to drive deep beneath the German position on the high ground while maintaining a horizontal profile. The use of compressors for drills and ventilation was considered vital for a working of this length, but 120–130 workers were still required for its construction over an eight-month period. Two side branches were used to protect the main attack gallery, which was descended from 35m to 40m to bypass the camoufleted area of German defences. The charge chamber was created by detonating a 500kg dynamite camouflet, concealed by simultaneously firing a second camouflet 60m away. Charging took ten hours, partly by truck and partly by human chain, during which jackhammers were used in the two flanking galleries to give the illusion of continued activity. The mine was fired on 4 May 1917, creating a 52m-diameter crater that bit into the German line, but the French made no attempt to capture it. (Public Domain)

A French mine gallery in the S system at the Butte de Vauquois, 120m in length and reaching to 36m beneath the summit. This was one of a series of deep inclined galleries begun from the rear slope; when it came into service in June 1917, the Germans were already deeper. Dug through the limestone gaize of the Argonne, an air ventilation pipe is secured on the upper left, while rails on the floor enabled spoil to be hauled out mechanically and dumped down the rear slope. The tunnels were restored by the Amis de Vauquois. (JEAN-CHRISTOPHE VERHAEGEN/AFP via Getty Images)

The French fired their last mine on 30 June, when they decided to discontinue mining at Vauquois, but it was extremely difficult to disengage. In June and July, galleries broke into each other, and the Germans dragged away a French sapper, then used explosives to seal off a section of gallery, leaving a gap in the French defences underground that took six weeks to repair. Between February and August 1917, despite the French desire to reduce mining, 38 German and 47 French camouflets were fired at Vauquois. In September, after it was hit by a German camouflet, the French blocked one of their deep galleries with barbed wire and abandoned it.

During the autumn and winter the French did not advance their tunnels beyond a centre line beneath the craters of no man's land. At Christmas 1917, the Germans shouted through a 1m thickness of tunnel wall, and the miners sang their respective national anthems until eventually the Germans fired a charge that gassed two French sappers. Although the French believed that their adversaries had also stopped active working, the Germans were still going deeper, reaching 95m by March 1918 and had begun chambering for a massive 200-tonne charge. In the expectation of major German offensives on the Western Front, however, the French were preparing to abandon Vauquois ridge and to destroy the mine networks. The last French charge was fired in March 1918, the last German charge in April. The French removed mechanical plant and blocked their galleries, allowing them to flood. In-depth defence meant that the Germans downgraded the importance of Vauquois and, by the time it was captured on 26 September 1918 during the Meuse–Argonne offensive, the garrison had been greatly reduced. The US 35th Division bypassed the ridge, which fell after brief but fierce resistance. Mining played little or no part in the German defence (Amis de Vauquois 2004: 302–15).

UNDERGROUND WARFARE AND TECHNOLOGY

Technological advance exemplified the gulf between civilian and military practice in mining in 1914. Although the British undoubtedly brought more civilian mining expertise into their tunnelling companies, France and Germany were more advanced in the development of the use of certain technologies such as powered drilling and listening devices. Electrical and compressed-air-powered equipment were used to remedy personnel shortages, but also in response to the harder geology away from Flanders, such as alpine regions where there was little alternative. Germany in particular used electrical power in preference to compressors, installing generators in support trenches to serve many of its mining sectors. For example, one at La Boisselle installed in March 1916 required a specially built dugout 220m behind the front line, with cables buried in the trench floor run up to the mine entrances that powered drills for shot bores, ventilation fans, water pumps and electric light (Sihler 1915–16).

Shot blasting was a common skill among miners and frequently used at the front, even though the noise could be heard for long distances. A series of boreholes were drilled into the face into which cylindrical containers of explosives were inserted and fired.

The noise was of less consequence when both sides were using shot blasting, and simultaneous firing could be used to conceal the location if necessary. Long bored mines were often used to fire smaller charges against trenches or as counter-mines. In an effort to save time and manpower, the French attempted to use a bored mine method to place a much larger charge at Vauquois in March 1916. An experimental Bornet electric drill, manned by the *Service électro-mécanique* from Versailles, was used to drill a long bore with a 15cm diameter. At the end of this, they detonated steadily larger charges to create a chamber capable of holding 10 tonnes of explosives. As they charged the chamber with gunpowder, however, there was a partial detonation in the explosive atmosphere, which luckily did not fire the 5–6 tonnes already charged. The French sappers were able to fire this charge, but did not repeat the practice (Amis de Vauquois 200: 234–38).

While the Germans used almost entirely electrically powered drills, the French favoured compressed air to operate hammer drills as well as for mine ventilation. In particular, much use was made of more compact compressor units developed immediately before the war by the American firm Ingersoll-Rand. In 1916, the French created the 8^{e} Bataillon du génie Mascart-Dessoliers (named after Charles F. Mascart, designer of excavation equipment and Louis F. Dessoliers, a public works contractor) to operate mechanized excavation equipment.

In the spring of 1916, French use of mechanization went some way to compensate for their falling behind the Germans in underground warfare. At the Argonne, the capacity of 12/15kW air compressors to power jackhammers, but which often had to be used for ventilation, was still inadequate. A plan at Vauquois in May 1916, to use mining involving compressed-air drills to blast a 130m gap in the German lines to gain French observation over the northern slope of the ridge, was still calculated to need 250 workers that were not available. The French increased their use of

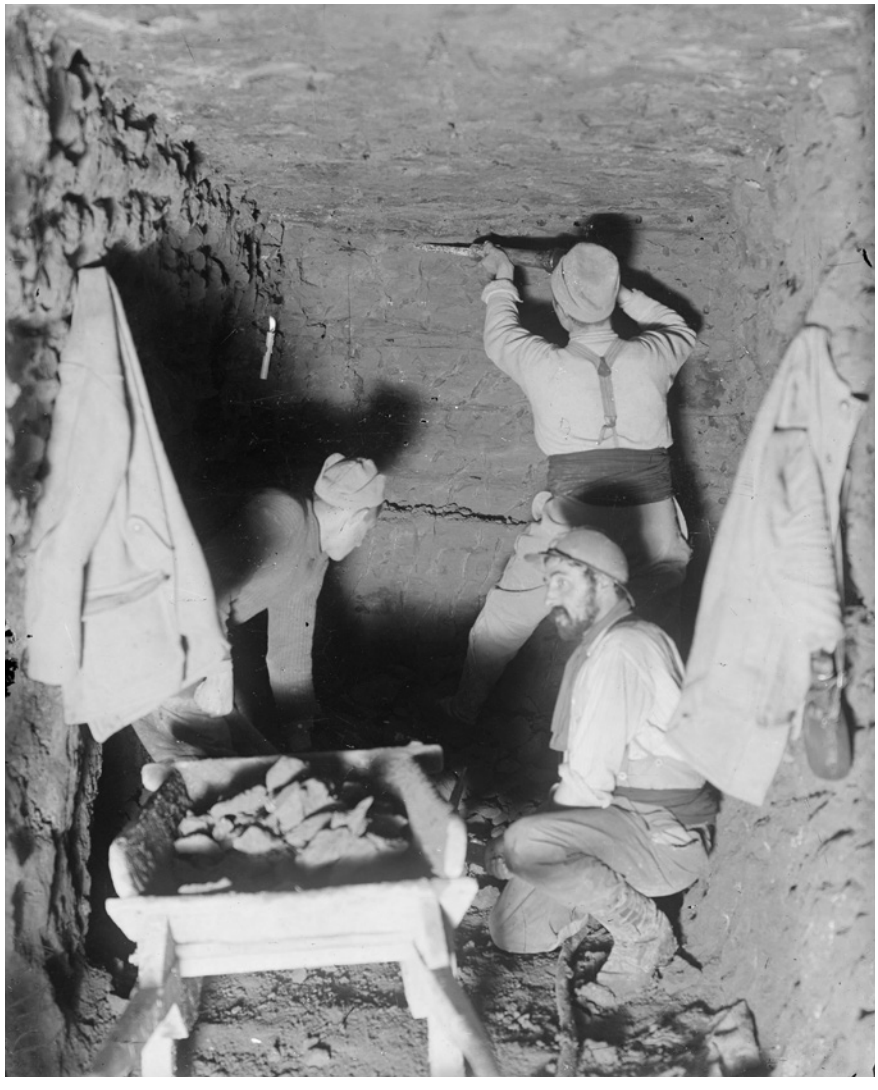
mechanization to compensate for the permanent lack of labour; by 1917, the workings at Vauquois were fed by 1,800m of compressed-air piping, but electrical capacity for haulage remained inadequate. Driving of the Mine Z galleries in the Argonne was carried out with jackhammer drills and shot firing. The main attack tunnel was driven by jackhammer to a point 27m from the German front line, where a charge chamber was formed rapidly by detonating dynamite charges. Shot firing was used in flanking galleries as a distraction and noise was also masked with intensive work in semi-deep galleries (Lazard 1932: 139–40).

In late 1915, Norton-Griffiths argued that the British could use drilling with compressors and shot blasting to mount a large-scale mining attack through chalk in Artois. This was begun in December by 170th Tunnelling Company, supplemented by half of 180th Tunnelling Company, but shot blasting was not justified at the 9m depth and rotary drills stuck in the chalk. The Hohenzollern Redoubt operation was entirely dug by hand. Shot firing was common in chalk at 24m or more depth. The commander of 179th Tunnelling Company at La Boisselle disliked shot firing, however, believing that it provoked the Germans, but had to accede to its use when both the Germans opposite him and the neighbouring 185th Tunnelling Company both adopted it. The British found hand boring the shot holes to be more efficient, but used compressors extensively for ventilation.

The British made little use of bored mines but experimented in 1915–16 with hydraulic jacks. The Barrett Forcing Jack and the Sentinel Pipe Pusher were supposed to force pipes through the ground that, when used to fire explosives, created communication trenches across no man's land. These were too easily deflected by hard ground, however, sometimes resulting in the pipe emerging several metres in the air. More effective was the 'Wombat' borer, brought to the Western Front by its inventor, Captain Stanley B. Hunter, with the Australian Mining Corps in March 1916. This drilled a bore of up to 16.5cm diameter to 60m, at a rate of 90–120cm per hour through chalk. This was a more effective method of creating communication trenches with explosive charges than the pipe pusher and was also used for ventilation holes in tunnels and dugouts. The formation of the Australian Electrical and Mechanical Mining and Boring Company from specialists who arrived with the Australian Mining Corps, did much to enhance the provision of electrical power in the front lines for the British Expeditionary Force (Finlayson 2018: *passim*).

Commercial tunnel-boring machines were tried for both military mining and

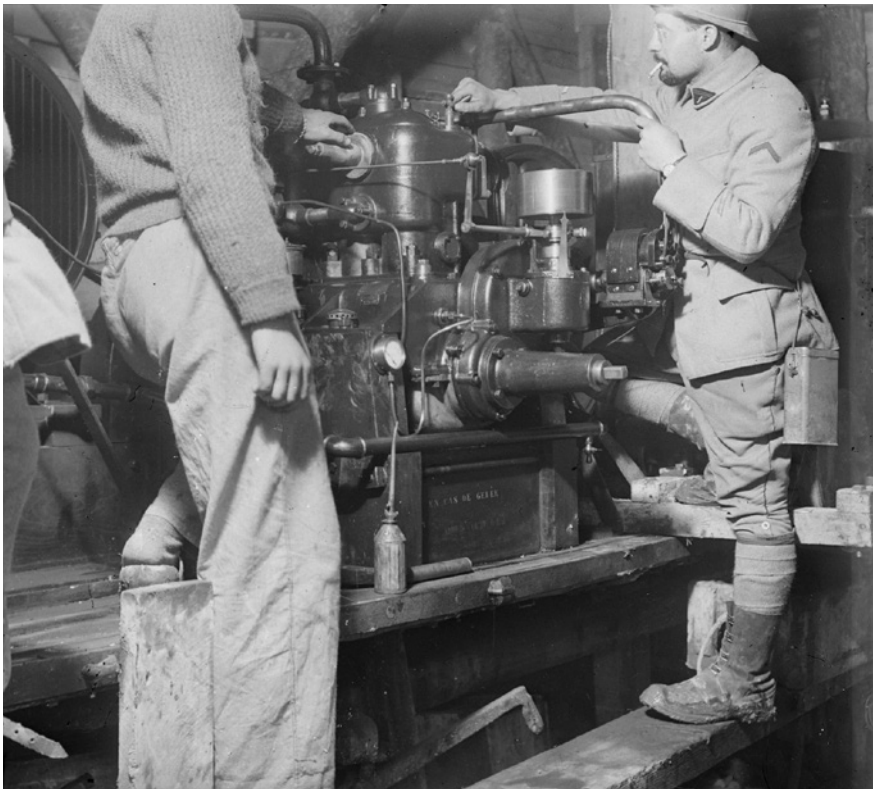
Pioniere operate a heavy-duty electrically powered drill. Driving through rock required heavier column-mounted equipment, such as this Siemens-Schuckert hammer drill. Smaller hand-held rotary drills by the same manufacturer were used for shot bores. The sounds of these drills did not necessarily travel any further than picking, while the progress achieved by drilling and blasting often outweighed the danger. (Author)



The Marchand tunnel, driven by French sappers with a pneumatic jackhammer drill towards the German position at Courte Chausse, 3 December 1915. The use of such power drills was a hazardous but fast means of driving through the limestone gaize of the Argonne. Here, the spoil is cleared into a wheelbarrow, but later in the war the haulage would be more efficiently organized with trucks on rails. (© Henri Bilowski/ECPAD/Défense)

dugout construction, but were rarely if ever successful. In 1915, the Pionier-Versuchs-Kompagnie of the Garde-Pionier-Bataillon was trained in Erkelenz in the Rhineland at the Internationale Bohrgesellschaft in the use of an electrically powered tunnelling machine. It was tried near Hill 60, south of Ypres, in August and September but was not a success. Cables, which had to be laid from a generating station established in a farm behind the lines, were repeatedly cut by shellfire. The machine had to be frequently halted to remove the build-up of mud and could not cope with the ground water and running sand (Held 1932: 264–65). The British made two attempts to use tunnel-boring machines in Flanders for the Messines mine attack, intending to drive through the clay in order to place mines deep behind the German lines. One was tried at the Petit Bois sector in March 1916, and another at the Bluff exactly a year later, but neither machine was successful.

All countries adopted commercial blasting explosives for military mining to replace traditional gunpowder, although shortages led to its continued use as late as 1916. The French favoured Cheddite, the Germans Westphalite and the British ammonal. The new explosives and the unprecedented size of



French underground compressor chamber for working in the mines, La Harazée, Argonne, January 1917. Compressors and power plants were installed near the entrances of mine systems, generally about 9m underground, and the compressed air piped to the face to power drills and for ventilation. (© Pierre Pansier/ ECPAD/Défense)

Grasern tunnel-boring machine in use by Austria–Hungary in Eastern Galicia in the winter of 1915/16. This machine appears to have been successful for constructing dugouts but seems not to have been used for military mining. (BTEU/ AUSMUM/Alamy Stock Photo)

charges meant that the old formulae for calculating mine charges were no longer applicable. The number of detonators required and the complexity of firing circuits was also without precedent. The largest British mine charge of 93,300lb (42,320kg) of ammonal, fired at St Eloi during the battle of Messines, was provided with three complete firing circuits of ten detonators each, plus 300lb (136kg) of gelignite priming (Royal Engineers 1922b: Pl. XXI).

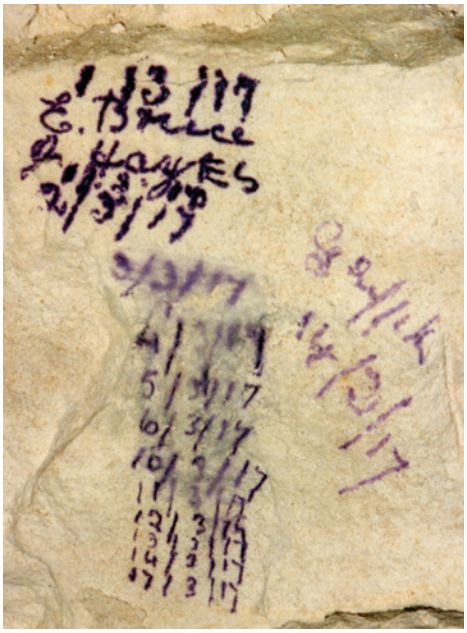
The Germans took the lead in developing technology for sound detection, which was to be a major game-changer in mine warfare. Underground, both sides were fighting blind, attempting to interpret the faintest sounds and to work out their distance and direction. The variations caused by geology could be deceptive to the inexperienced, however. With the naked ear, picking could be heard up to 45m away in chalk but only 6–9m away in sandy soil. A man walking could be heard at 9m in chalk or 1.5–2.5m in sandy soil;

A hand-operated ventilator in use in a dugout on the Eastern Front, cranked by an *Unteroffizier* from 1. Niederschlesisches Landwehr-Regiment Nr. 46. Mechanical ventilators were vital for mine galleries of any length but could be noisy. British mining engineers favoured creating natural ventilation and quieter hand-operated blacksmith's-type bellows over powered fans but used compressors where available. (Brett Butterworth)

his voice could be heard through 3.5m of chalk or 60–90cm of sandy soil (Mining Note No. 12, Inspector of Mines 1916–18). Prolonged listening enabled miners to build up a picture of their opponents' working habits and activities. In particular, danger signs could be recognized, such as two men picking at once, suggesting the enlargement of a chamber to hold a mine charge, or of loaded spoil trucks being pushed up to the face, rather than away from it, indicating explosives and tamping being brought up. If such activity were followed by silence, there was a certain chance that a charge had been laid and that it would be fired imminently. Familiarity with these signals led miners to conceal their activities with false noise; in particular, the tell-tale silence preceding a mine detonation would be covered by noise from adjoining galleries, even with the use of dummy picks. To allow listening to be carried out without distraction from their own activity, units regularly paused work for around 30 minutes or more. It required extraordinary self-control to crouch or lie alone for long periods of time to try to determine whether an explosion was imminent, in the knowledge that the enemy was close by.

The Germans were the first to develop electrical microphones as mine listening devices and, by August 1915, had issued the Edelmann, Schmidtmann, Knieriem and Waetzmann types. In addition to their use at the tunnel face, up to ten microphones could be monitored by an NCO at a central listening post at the shaft house (Stellvertretendes Ingenieur-Komitee 1915). Microphones would be installed with explosive charges when they were tamped, so that enemy activity could be monitored to judge the most suitable time for firing.

In the chalk of the Somme or Artois, mid-1916, a British tunnelling officer uses a Geophone while two miners appear to be tamping a charge. The photograph may be posed, as the Geophone would be impossible to use while there was activity in the same chamber, but their anxiety appears genuine. Charging and tamping were extremely hazardous owing to the tell-tale cessation of picking, and the men may have paused momentarily to allow the officer to listen. The lieutenant has turned his cap around and appears to have only one Geophone disc connected. An electric CEAG safety lamp, used for rescues and when working in gassy galleries, has replaced the candle in the niche. (Chronicle/Alamy Stock Photo)



Graffiti left by listeners of 172nd Tunnelling Company in a chamber in close proximity to the Germans beneath Vimy Ridge, March 1917, a period immediately prior to the assault and capture of Vimy Ridge on 9 April 1917. Listeners needed a phlegmatic temperament, without an overactive imagination. The graffiti reveals their identities and shows that there was a small number of men employed in this role, working regular shifts in the same locations, and in pairs. A Seismo-Microphone was also used for listening in this chamber and was recovered for the Royal Engineers Museum when the author visited in 1989. (Author)

The French developed both electrical microphones and devices that used stethoscope earpieces, with early types made by F. Ducretet et E. Roger, Paris. Containers of water were used to amplify vibrations, both in proximity to a microphone in the so-called 'Water Electric' detector, and the simplest device which was a French metal water bottle to which was attached stethoscope earpieces. The French water bottle was the most common type of listening device used by the British tunnelling companies in mid-1915. Later in the year, the British introduced the Sadlier-Jackson and Western Electric microphones, but they were not particularly popular with tunnellers. Two French listening devices that used a similar principle appeared in later 1915, however, and were to prove successful. Invented by Jean Perrin, the professor of physical chemistry at the University of Paris, the Geophone Système Perrin used two discs containing mercury or lead, enclosed between mica membranes, to amplify minute vibrations to which the user listened through stethoscope earpieces. Perrin's invention was capable of increasing the listening range by about 2½ times and was immediately popular with French and British miners. A listener with training and aptitude could use Perrin's Geophone to detect both distance and direction, taking bearings towards sound from more than one listening gallery.

The second device was the Seismo-Microphone TM, an electric version developed by the Service de la telegraphic militaire; although it lacked the

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LISTENING AND DECEPTION DEVICES

(1) The German Knieriem apparatus, 1915–17

This *Pionier* listens using telephone earphones to vibrations from a steel rod inserted into the tunnel wall that have been amplified by a weight connected to a battery-powered microphone. Mine safety lamps of this type were manufactured by Friemann & Wolf.

(2) The French Geophone Système Perrin, 1915–18

The two discs were placed on the tunnel floor, one connected to each of the listener's ears by a rubber tube and metal stethoscope earpiece. If a listener was lying down, he first had to become accustomed to the Geophone detecting his own racing heartbeat, or the creak of a leather belt, before he could begin to recognize the amplified vibrations. The open box contained a compass that could be placed between the two discs when establishing direction. This officer wears a Modèle 1915 Adrian steel helmet, and a Modèle 1915 other-ranks jacket bearing the collar patches of an *adjoint du génie* (assistant engineer) and the rank bars of a *lieutenant*.

(3) German device for simulating picking and shovelling

Captured by the British in July 1916, this device was used by the 2. Reserve-Kompagnie, Württembergisches Pionier-Bataillon Nr. 13, at Mametz on the Somme. This apparatus was designed to be placed at the working face of a mine gallery to deceive the British into believing that the Germans were still at work. The most common reason for this would be that the sounds of continued activity would disguise the fact that miners had withdrawn owing to a charge having been placed close by. A heavy pick on leaf springs was pulled back by a rope and allowed to strike the face. In addition, rotating the screw device attached to the base simulated the scraping sound of shovelling. Dummy picks were often resorted to, though they were frequently suspected by listeners and could not be used for long as the tunnel face would remain suspiciously static (Mining Note No. 34, Inspector of Mines 1916–18).

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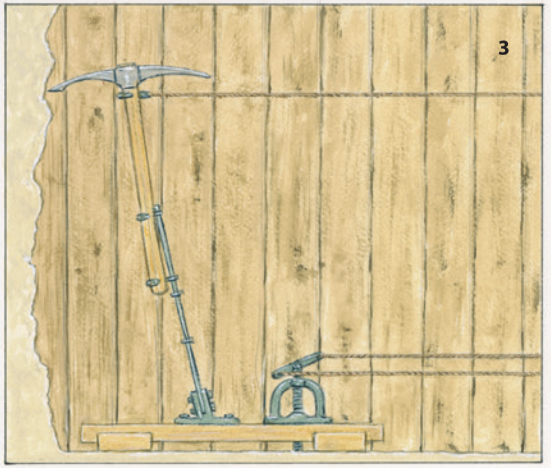

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sensitivity and stereo capacity of Perrin's Geophone, it was effective for remote monitoring. Both the Western Electric and the Seismo-Microphone could be monitored from central stations, with a system of lights that registered activity on a plan of the mine workings. Until mid-1916, however, British tunnelling officers were slow to trust in the use of central listening stations, preferring to use the Geophone at the face (Jones 2010: 177–79). A study by the author of casualties suffered at La Boisselle has shown that this reliance on human listeners resulted in considerably more British than German casualties.

The danger during military mining of asphyxiation due to the gas produced by underground detonations was well-known before the war. With the escalation of mine warfare and the increasingly large size of charges, however, this became a serious and widespread hazard, with miners frequently collapsing and even dying. Professional miners, well accustomed to the dangers below ground of reduced oxygen, were taken by surprise by the quantity of especially carbon monoxide produced by underground explosions. This gas, colourless and odourless, soon became the most frequent killer underground and could only be protected against with self-contained breathing apparatuses. It also remained trapped underground, when repeated camouflet explosions left terrain 'gas-logged', liable to be released if broken into or when atmospheric pressure lowered. Time and again, men descended underground to rescue a comrade who had collapsed, only to succumb themselves. Methane, also a product of underground explosions, was a serious hazard that led to secondary detonations and fires (MacPherson 1923: 532–82).

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MINE RESCUE BREATHING APPARATUSES

(1) German Dräger M1910/11 breathing apparatus

This pre-war civilian model, designed in particular for mine rescue, was capable of one- or two-hour protection. A steel facepiece protects the front of the head; the air cylinder and sodium carbonate container were worn on the back. Although it was issued to German *Pionier* units, it was too bulky for rescue work in the small dimensions of mine tunnels.

(2) German Leipziger Atem-Schutz-Apparat (Leipzig breathing apparatus)

Equipment such as this asbestos firefighter's smoke helmet, which was issued to *Pionier* units, did not carry their own self-contained air supply but relied on an airline to the surface. As such, they could have been of very limited use in mine warfare, but may have had some value when fighting dugout fires.

(3) German Heeres-Sauerstoff-Schutzgeräte (Army Oxygen Breathing Apparatus), 1916–18

In 1916, Bernhard Dräger of Drägerwerk designed a larger version of the *Selbstretter* (self-rescuer) for the military which provided 60 minutes of protection. Designed to be less bulky than the M1910/11, the type's air cylinder and sodium carbonate container were worn on the left side at waist height, with the air bag below.

(4) French Draeger breathing apparatus, 1915–18

This pre-war French copy of the Drägerwerk *Selbstretter* was initially issued for protection against poison gas. By the end of 1916 it was mostly issued to medical and engineer units for mine rescue, and the design was modified to aid movement underground in a squatting position. It was issued in large numbers but, due to its duration of only 30 minutes, engineer companies did not regard it as being suitable for rescues in galleries longer than 100m. Replacement designs were rejected as too bulky until, at the beginning of 1918, the *appareil respiratoire MCG modèle 1917* or *Fenzy petit modèle*, began to be issued.

(5) British Proto apparatus in use, 1916–18

Here, a British rescue man in Proto apparatus aids a casualty being hoisted up a shaft on a mine stretcher. The Proto breathing apparatus could protect the wearer for up to two hours. With the carbonate of soda cartridge on the chest, air bottle on the lower back and air bag on the front, it involved less encumbrance than other apparatuses but allowed a long duration. Each tunnelling company had two mine rescue men permanently on duty in a Proto dugout in the mine system. Use of the breathing apparatuses necessitated thorough training and each army in the BEF had a mine rescue school at which Proto men had to pass an eight-day course.

This Proto man carries a canary, used to detect carbon monoxide; the claws were kept clipped so that the bird would immediately fall from its perch if poisoned, but canaries usually recovered once taken into fresh air. The mine stretcher was designed in 1916 by Lieutenant John Penman, in charge of the Third Army Mine Rescue School. The ropes allowed a casualty to be secured for hoisting up a shaft but also, because carbon monoxide poisoning often caused victims to become violent, allowed him to be restrained (MacPherson 1923: 580–82).

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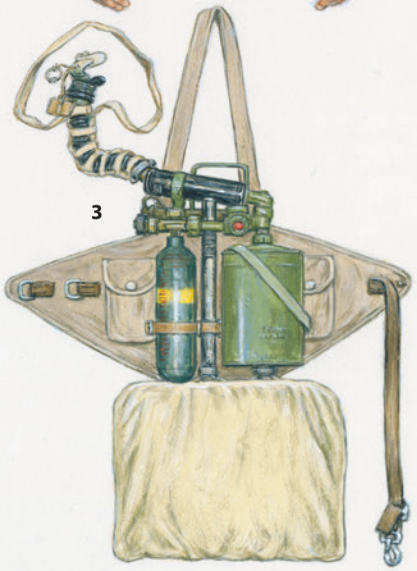

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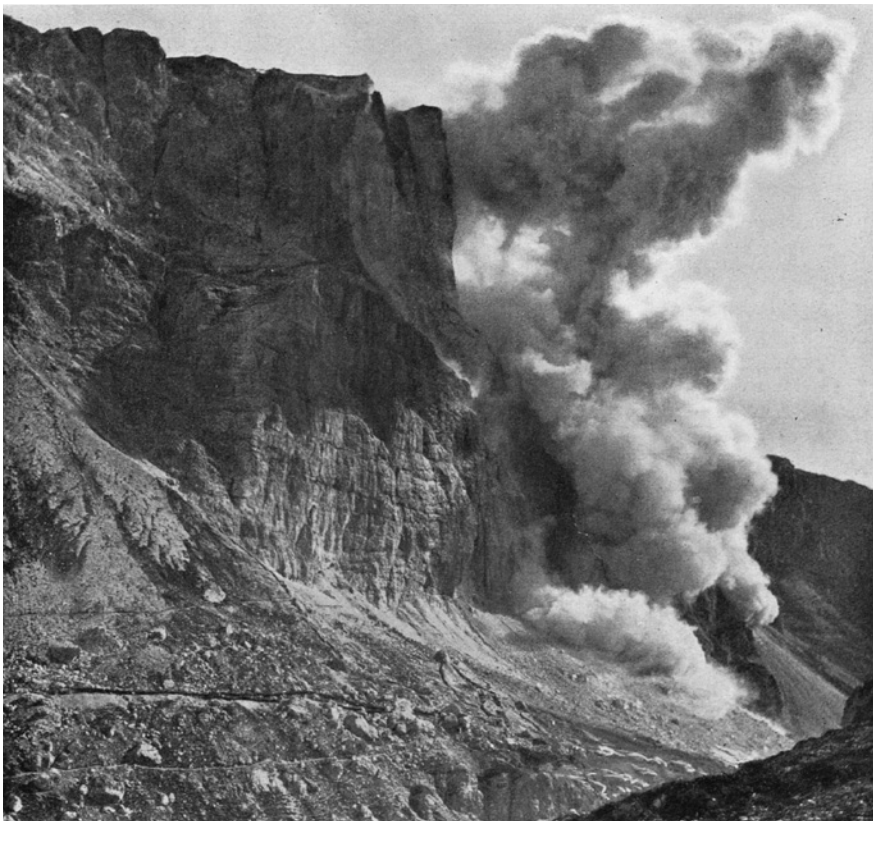
At a central listening station in the mine system at La Harazée, Argonne, French engineer officers monitor Seismo-Microphones placed in the tunnel faces for signs of abnormal German activity, January 1917. The electrical microphones were not as sensitive as the Geophone Système Perrin, but enabled far more locations to be monitored, and spared both the nerves of listeners and also their lives. (© Pierre Pansier/ ECPAD/Défense)

At first, primitive commercial types of 'smoke helmet', consisting of leather or asbestos hoods fed via a long pipe from a hand-operated air pump, were issued but were of little or no use for mine rescue. As with other mining technology before 1914, the development of civilian rescue equipment had rapidly outpaced military knowledge in terms of manuals and service equipment. At the beginning of the 20th century, self-contained breathing apparatuses had been developed using sodium carbonate to 'scrub' the carbon dioxide from exhaled air, which would be topped up with compressed air from steel cylinders and combined in a breathing bag. Versions of this apparatus by Drägerwerk were produced in Germany and under licence in France, and also in Britain by Siebe, Gorman & Co. Large numbers of the smaller versions of this apparatus were already issued from May 1915 by Germany, France and Britain, following the first German chlorine gas attacks. The German *Selbstretter* (self-rescuer) *Dräger-Tübben 1913*, a French copy and the British Salvus apparatus by Siebe, Gorman & Co., all provided 30 minutes of protection (see Jones 2010: 33, 60). These were also issued for mine rescue purposes, although their duration was only sufficient for simple rescues. The larger 'Proto' apparatus produced by Siebe, Gorman & Co. was found suitable for British tunnelling companies, while Germany and France developed bespoke apparatuses for mine rescue (Haase-Lampe 1924: 180).

MINING ON THE ITALIAN FRONT

When Italy entered the war on the side of the Allies in May 1915, a front opened up on the Tirol and along the Isonzo River, which was to see extensive underground warfare between Italian and Austro-Hungarian forces. Rock drilling powered by compressed air or electricity was essential on much of this front for military mining, the construction of trenches, troop shelters and logistical assets, and for tunnelling artillery positions high in the mountains. By June 1918, there were 510 Austro-Hungarian *Gesteinsbohrzüge* (rock-drilling platoons). The single most remarkable Italian logistical project was the 6.5km-long *Strada delle 52 gallerie*, the road of 52 tunnels, built by the 33ª Compagnia minatori and 600 attached labourers during February–November 1917 to supply the fighting at Mount Pasubio. The most dramatic of the tunnels – but, at 86m, by no means the longest – was the spiral ascent of Tunnel 20, named after Generale Luigi Cadorna, the Italian Army chief of staff.

Ice tunnels were also a major feature of alpine positions for concealed access and accommodation. Within the Marmolada Glacier in the Dolomite Alps, the *Eisstadt*, or Ice City, included 12km of tunnels dug by the Austro-Hungarians in 1916, accommodating 200 soldiers, kitchens, stores, medical facilities and a chapel. In the Ortler Alps, where there were 11.4km of ice tunnels dug by both sides, a firefight broke out when *Alpini* (mountain troops) broke into an Austrian attack tunnel in March 1917, while the Austrians stormed the almost impregnable Trafoier Eiswand mountain using a 1,400m tunnel dug through glacial ice (Isitt 2022).



Published shortly after the war (Schemfil 1926: 336), this photograph depicts the explosion of a 16-tonne Austro-Hungarian mine at Lagazuoi on 14 January 1917. An unsuccessful attempt by the Austro-Hungarians to create a landslide over Italian positions created a crater 37m wide and 45m deep, but most of the force of the explosion was taken into the Italian counter-mine. Two subsequent Austro-Hungarian explosions at the same location in 1917 brought down massive quantities of rock, but did little to improve the Austro-Hungarians' situation. (digi.landesbibliothek.at/CC BY-SA 3.0)

Italian soldiers occupy a mine crater, said to be Col di Lana, subsequent to its firing on 17 April 1916. Italian miners under the command of Tenente Gelasio Caetani, a graduate of the Columbia University School of Mines in New York, charged two chambers with over 5 tonnes of explosives, which when detonated formed an elongated crater 25m wide, 35m long and 12m deep. Col di Lana was the first Italian mine of the war and its most devastating in terms of casualties, killing over 100 men of the 2. Tiroler Jäger-Regiment 'Kaiserjäger', many of whom were buried beneath the rubble. A battalion of Italy's 59º Reggimento fanteria stormed the summit and captured 170 prisoners. Some consolidation of the crater had taken place when this photograph was taken. (DEA/ICAS94/Getty Images)

Where mine warfare was employed to attempt to gain control of the highest mountain peaks, the massive explosions were to alter their outlines permanently. Between January 1916 and March 1918, there were some 20 Italian and 14 Austro-Hungarian mine explosions in the Dolomite Alps, focusing on the highest peaks of Monte Pasubio, Lagazuoi, Col di Lana, Monte Sief and Marmolada. The Caporetto retreat of November 1917, after the Austro-Hungarian–German breakthrough on the Isonzo front to the east, curtailed many preparations on both sides on the Dolomite front, with only Pasubio remaining active. The final mine here was also the largest, an Austro-Hungarian charge of 50 tonnes matching the largest German and

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MINING ON THE ITALIAN FRONT

(1) Italian miners at Castelletto, March–June 1916

Here, miners of the Battaglione 'Belluno' of the 7º Reggimento alpini, their membership of the unit indicated by the green *nappina* (small woollen ball) on the side of the *cappello alpino*, use a compressed-air drill during the Castelletto mining operation. Two compressors were installed in the Castelletto tunnel system, one near the entrance, and a second, smaller unit deeper inside. The compressed air was conveyed through the workings by rigid iron pipes, connected to the drills by flexible metal hoses. The drill is an American Ingersoll-Rand Butterfly jackhammer drill. About 100 miners worked six-hour shifts, limited in duration owing to the dust and fumes from shot firing, achieving an average progress of 5.1m a day. Illumination is by carbide lamp. The mining engineer Eugenio Tissi commanded a platoon of the 78ª Compagnia of the Battaglione 'Belluno'.

Italian insignia

Insignia depicted here include an embroidered *cappello* badge of the 7° Reggimento alpini (**2**) and an officer's embroidered cap badge (**3**) and arm badge (**4**) of the 5° Reggimento genio minatori, a mining regiment that mobilized nine battalions during the war. The arm badge depicts crossed rock drills, a cogwheel and sparks.

Austro-Hungarian insignia

The *Gesteinsbohrabzeichen* (**5**), a collar and cap badge worn by rock-drilling units, depicting a rock drill and crossed miners' hammers, was approved on 31 May 1917; this silver-plated version was worn by enlisted men, while a gold version was worn by officers. The semi-official badge of the *Gesteinsbohr-Bataillon* (**6**) was worn on the side of the field service cap.

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French mines on the Western Front. The explosion buried about 40 Italian soldiers, while flames shooting through tunnel networks caused casualties to both sides (Striffler n.d.).

The mining of the Castelletto saddle in the Tofane mountain group was carried out by members of the Battaglione 'Belluno', an *Alpini* unit independent of the *Minatori* units of the Italian Army's engineers, but with the approval of the engineer command. The personnel were almost all experienced miners from the Belluno area in northern Italy who had worked in Westphalia, Austria and France. The operation was conceived by Sottotenente Eugenio Tissi, a graduate of the Agordo mining school who had also studied at the Bergakademie in Berlin, although he was to be severely wounded and evacuated before it was completed.

Approved in December 1915, the operation first required an access route to be created, which involved blasting about 250m of tunnel and the removal by hand of about 600 cubic metres of rock. Observation points had to be established using ropes and rope ladders, and a 116m base line measured for a trigonometric survey to enable accurate direction of the tunnels. From mid-February until the end of March 1916, a chamber for machinery was dug and the first 14m of tunnel excavated by hand. A 22/30kW petrol engine and Sullivan compressor were broken down into loads of up to 600kg and carried through heavy snow up to the chamber. Subsequently, a smaller Ingersoll-Rand compressor with an 11/13kW engine was brought up and installed further along the tunnel.

The Austrians heard the Italian drilling in March but failed to recognize it as a mining attack. After the detonation of the first large Italian mine on 17 April 1916, however, 7.5km away at Col di Lana, they became alert to the danger of further mining attacks. Recognizing Italian shot firing under the Castelletto saddle, the Austrians began counter-mining. Then on 8 June, the Austrians spotted a 50cm-square opening that accidentally broke out on the mountain face, before the Italian miners quickly blocked it. When the Austrians began drilling 50–60m from this point, their proximity forced the Italians to abandon two planned charges each of 16 tonnes, for a single one of 35 tonnes. When, on 3 July, the Italians began charging, the tunnel was almost 400m in length. As they did so, they could hear the Austrians seemingly only a few metres away. After three days, however, the sounds ceased when, lacking effective equipment, the Austrians were forced to stop work. The Italians tamped the charge for 33m, 21m of which was concrete, completing work on 9 July.

When they fired the mine, at 0330hrs on 11 July, the explosion killed 13 Austrians and blew a large crater in the saddle. Carbon monoxide gas released into the Italian tunnels caused all of the miners to lose consciousness, although all but one were revived by the medical officer. The explosion also did not behave entirely as the Italians had anticipated. Instead of hurling the debris towards the Austrians, it mostly fell on the Italian side. Then, as the *Alpini* attackers attempted to climb up to the Castelletto saddle, the mass of loose mine debris gave way beneath them like flaking plaster, preventing them from gaining access to the crater. It was initially occupied by the Austrians and only after two days' fighting were the *Alpini* able to capture the crater and saddle from the exhausted Austrian garrison. The Castelletto mine was heralded as a success in the Italian press although, as with many mining attacks, the results may not have justified the effort expended (Sappeur-Offizier 1937).

OPPOSITE
An Italian *Alpini* miner in the *Polveriera interna* (explosives magazine) in the Castelletto mine system, 1916. Holding detonating cable, he is seated on boxes of dynamite used for shot blasting. At first this was carried out by using *Gelatina militare*, but subsequently the Dinamite n.1 visible in this store was employed instead. The carbide lamp in front of him has a naked flame. (Biblioteca di Storia Moderna e Contemporanea)

DYNAMITE

DUGOUTS, SHELTERS AND ATTACK TUNNELS

Underground shelters were developed as part of trench warfare, and by spring 1915, German dugouts had 5m of cover to protect against shellfire. The Germans undertook a programme of dugout building in 1915–16 that enabled them to accommodate large numbers of troops in the front line with cover of up to 9m. This made the German positions extremely difficult to capture and in particular enabled them to repel much of the opening British attack on the Somme on 1 July 1916.

Both sides also used existing caves, in particular the many underground limestone and chalk quarries in the Champagne, Aisne, Somme and Artois regions, to accommodate troops and other facilities in the area of the front lines. Troops massing for the attack were also sheltered in caves and tunnels. As preparation for their offensive at Verdun on 21 February 1916, the Germans constructed broad *Stollen* (tunnels) which were 9–14m deep with steps leading up to communication or assault trenches. In this way, some 12,000 German troops were concealed in the woods of Consenvoye, ready to follow the initial assault waves.

Tunnels were also tried as a means of enabling the attacking infantry to advance, a method common in siege warfare, in which saps covered with earth or logs were dug towards enemy positions. In 1915–16, there were frequent attempts to sap forward across no man's land in traditional siege practice, using both surface saps and tunnels with about 1m of headcover. The latter, known as 'Russian Saps', could be broken open to form trenches, thus creating a new front line closer to the enemy. The French used this method during the Third Battle of Artois in August and September 1915, in order to approach Vimy Ridge under German observation. When the French

An operation in progress in an underground surgical hospital, Souain, Champagne, August 1916. Constructed in April and May 1916, the hospital was just 2.2km behind the front line. (© Albert Samama-Chikli/ ECPAD/Défense)

Dating from *c.*1916, this French battalion commander's dugout, about 600m behind the front line in the Champagne sector, is preserved at the Museum at La Main de Massiges. By 1916, curved sections of corrugated iron, known in the British Army as 'elephant iron', were commonly used by all belligerents to support shallow cut-and-cover dugouts. The earth headcover of about 2.5m was reinforced with logs, rails or girders. (Author)

attempted to attack from the broken-open saps, however, they suffered heavily after the Germans identified the openings and picked off the attackers as they emerged.

Similar shallow tunnels were used for sapping operations at the same time at the Anzac position on the Gallipoli peninsula. At Lone Pine, Australian engineers linked seven saps to form an underground front line in no man's land, 35–55m from the Ottoman positions. On 6 August, the leading companies of three Australian assaulting battalions attacked from this line by opening recesses in the tunnels, going forward to assault Ottoman positions that were themselves also covered with logs and sand. Another attempt at Gallipoli to attack from tunnels was made by British troops at Krithia Nullah on 19 December. The Ottoman forces quickly directed fire on the narrow opening on a cliff face, however, causing heavy casualties.

The idea that tunnels could actually be used to enable attackers to emerge behind the enemy lines gained supporters in the early years of the war, despite the obvious drawbacks. At Anzac, a scheme was approved for two deep tunnels to be driven at the Nek position into the rear of the Ottoman lines. Under the superintendence of Captain Harry F. Arnall, a Cornish-born New South Wales miner, the supposedly secret project became known as Arnall's Folly, but was not complete by the time of the evacuation.

The British made extensive use of shallow Russian Sap tunnels on the Western Front during 1916, preparing more than 40 for the opening of the battle of the Somme. These were not, as is sometimes thought, the means by which the attackers would emerge at zero hour. First, they were used to create firing positions for mortars and machine guns in no man's land to increase the fire on the German front line during the crucial last moments of the assault. Second, the tunnels were to solve the problem of holding the former German front line after capture, when the attackers would be at their weakest, cut off by German fire from resupply and subject to often-effective German counter-attack. The Russian Saps, either as tunnels or broken open, would provide a covered passage for signals cable, ammunition, water supply, and even

The night shift of the New Zealand Tunnelling Company in their bunks in a quarry about 18m below ground at Les Fossés Farm, 5 December 1917. This unit was withdrawn from front-line mining in October 1916 to prepare caves and tunnels for the British offensive at Arras. Afterwards it continued work on underground accommodation and fitted out this cave 8km south-east of Arras to accommodate 400 men. (Alexander Turnbull Library)

infantry reinforcement, to enable the attackers to hold on. More than 40 were prepared, but only two were of real use in the fighting. In the south they were not required because the German front line was successfully captured, while in the north, the German lines were barely entered and the Russian Saps were of no use. Only at the Leipzig Redoubt and south of La Boisselle were they of value in supplying British troops who had gained a toehold in the German lines. During the subsequent Somme fighting, the use of Russian Saps was refined and when it came to planning for the battles of 1917, their role was more clearly understood in the process of organizing, concealing and conveying troops to their points of assault (Jones 2010: 190–213).

In 1917, the British renamed Russian Saps 'subways' to reflect their role, which was to convey troops up to the front line, and prepared large numbers

The accommodation of a German *Kampf-Truppen-Kommandeur* commanding the front-line troops, reconstructed in the *Caverne du Dragon*, Chemin des Dames ridge. The *Caverne du Dragon* was held by the Germans from January 1916 until they were driven out of the forward part in 1917 during the Nivelle offensive and built a stone-and-concrete barricade across the cave. On 25 June, the French released phosgene gas into the cave, attacked it with flame-throwers and blocked the northern exits with artillery fire, resulting in the surrender of 200–250 German soldiers. A month later, the Germans recaptured some of the northern exits and the cave was again in dual occupation until the French took the entire ridge in November 1917. (Author)

for the Arras and Vimy Ridge offensives, launched on 9 April. The Canadian Corps' successful attack on Vimy Ridge was facilitated by 12 subways of 275–1,720m in length, which enabled the attackers to be conveyed to their jumping-off trenches safe from German observation on the ridge. In a series of linked underground quarries at Arras, some 11,500 troops were accommodated prior to the British attack on 9 April. Two tunnels enabled troops to move underground from the centre of Arras to the front line, although the southern tunnel was rendered ineffective by the German withdrawal to the Hindenburg Line shortly before the offensive was launched. From 1917, the capacity of the British tunnelling companies was increasingly used for the construction of subways and dugouts and for general logistic work.

During 1916, the Allies developed sufficient infantry–artillery coordination to allow them largely to defeat the German deep front-line dugouts, trapping the defenders underground using creeping barrages and mopping-up troops. By late 1916, this prompted the Germans to change their defensive policy, instead holding their front lines with fewer men. In 1917, however, the Germans were still using tunnels extensively, both to accommodate support troops and to enable them to reach the front line, linking their first and second or third lines for the purposes of counter-attack. At Vimy Ridge on 9 April, parties of tunnellers and Canadian troops were tasked with locating the entrances of two long tunnels 520m and 1,350m in length, and trapping the occupants before they could emerge. Inside the longer tunnel, they captured 150 men, many still half-dressed and unaware of the attack (Buhr 1938: 160; Jones 2010: 235–36).

On the Chemin des Dames ridge, attacked during the French Nivelle offensive on 16 April, both sides made use of *creutes*, underground quarries in the white limestone, while the Germans had also dug numerous communication tunnels through the summit. On the eve of an attack on the ridge on 4 May, a French shell hit the main entrance of the Winterberg tunnel, blowing up an ammunition store and trapping personnel inside, resulting in the death of 100–150 men. The most infamous *creute* on the Chemin des Dames was beneath the German front line, linked by a tunnel to a smaller

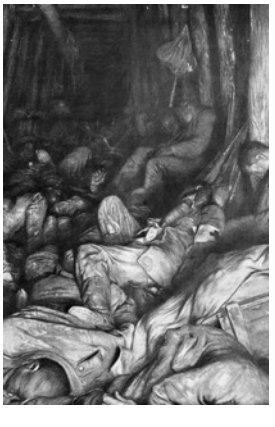
French engineers in the Kronprinz tunnel on 21 August 1917, the day after its capture. One of three German tunnels constructed over a nine-month period in 1916–17 on the Morte Homme position, Verdun sector, the Kronprinz tunnel provided communication for 900m through the hillside, as well as accommodating command and support facilities, and bunks for two companies. Prior to attacking the position, the French bombarded the tunnel with a 40cm rail gun, achieving two direct hits on 19 August that smashed in the roof, killing almost 200 men. When the French attacked the following day, the 81e Régiment d'infanterie captured 600–700 prisoners from the tunnel. (© Albert Samama-Chikli/ ECPAD/Defense)

Argonne, 1917–18: German machine-gunners from the Württembergisches Landwehr-Infanterie-Regiment Nr. 125 exit via a tunnel entrance, demonstrating how it enabled defenders to come into action rapidly. The tunnel is almost certainly the 350m-long Kaisertunnel, which provided passage 40m beneath the Kronprinzenhöhe, enabling the support company to reach the front line at La Fille Morte. By the time this photograph was taken, however, such tunnels were highly vulnerable to Allied attack tactics and were ordered to be destroyed by the beginning of a battle. The notice states that, in the event of a major enemy attack, the tunnel was to be blown up on the orders of the regiment. The Germans destroyed the Kaisertunnel two days before the position was captured during the Franco-American Meuse–Argonne offensive on 26 September 1918. (Brett Butterworth)

cave under the third line whose name, the *Drachen-Höhle* or *Caverne du Dragon*, came to be used for the whole complex. Capable of accommodating well over a battalion, it changed hands repeatedly during 1914–18.

Like the deep dugouts in the front line, in 1917 the German communication and accommodation tunnels were also rendered death traps by Allied tactics. When, in April and May 1917, their attempts to capture Mont Cornillet failed during the Third Battle of the Champagne, the French learned from prisoners that the Germans were using a system of tunnels beneath the hill. This included three linked parallel tunnels, each 120–143m in length, capable of accommodating three battalions able to launch strong counter-attacks. When the French attacked again on 17 May, they targeted the entrances and ventilation shafts with intense high-explosive and gas shelling, trapping troops inside and causing carbon monoxide and phosgene gas to build up. Three days later, the French captured the hill and, entering the tunnel, found it filled with the bodies of asphyxiated soldiers. An unknown number of troops from two battalions of the Württembergisches Infanterie-Regiment Nr. 476 and two platoons of Pionier-Kompagnie Nr. 376 were killed by carbon monoxide and phosgene gas. The tunnel remained sealed until 1974–75, when *Pioniere* of the West German Bundeswehr, assisted by the French Army, recovered the remains of 321 soldiers (Knies 1927: 114–17; Jones 2010: 237–43).

The interior of the German Cornillet Tunnel, Champagne, after capture by the French on 20 May 1917. (imageBROKER.com GmbH & Co. KG/Alamy Stock Photo)



In June 1917, the Germans attempted to reaffirm their new defensive doctrine, ordering the destruction of any deep dugouts still remaining in the front line by the beginning of a battle at the latest, and the destruction of sections of large tunnels to reduce their size. Yet this order was counterintuitive for many German commanders and seems to have been disregarded. The order did not prevent a catastrophe the following month, however, when the French attacked the Morte Homme position in the Verdun sector. Having identified the location of tunnels through the hill, the French bombarded the Germans with super-heavy artillery prior to attacking on 20 August, achieving two direct hits and collapsing part of the Kronprinz tunnel, killing almost 200 German troops and causing the surrender of the remaining garrison. By the time of the Allied offensives of September 1918, the German communication tunnels were so vulnerable that orders for their destruction were more likely to be taken seriously, as in the case of the Kaisertunnel in the Argonne.

CONCLUSION

Civilian industry and a mass workforce propelled underground warfare to a peak during World War I that remains unsurpassed. Voluntary enlistment in 1915 meant that Britain was best able to incorporate civilian expertise into its mining units, but in several respects Germany and France used technology and mechanization more effectively to complement human capacity and skills.

Yet mining reinforced rather than broke the deadlock of trench warfare, even while the opposing sides had little choice but to engage in it if they were to keep their defensive lines intact, preserve the status quo and enable their men to survive. Commanders used mine warfare in the full awareness of how wasteful it was in terms of manpower, even though this was in increasingly short supply for both logistics and combat. The use of the slow methods of a siege in trench warfare could not achieve decisive results because a breach did not lead to surrender, as it could for a fortress, merely the withdrawal to the next line behind. Attrition is a far more normal state of warfare than is often supposed. The use of military mining as part of trench warfare, however, where the effort exerted was not rewarded with commensurate benefit in terms of either tactical improvement or wearing down of the opponent, was a very ineffective form of attrition.

Why did the British persist with mining when the French and Germans were trying to stop it? First, in 1915, in the absence of heavy artillery, mining was the only sure means of breaching trenches. Second, the effectiveness of the British and Commonwealth tunnelling companies gave the British command a means of destroying the German front lines, which was a devastating weapon of shock and terror. By 1917, however, the front line was no longer the key to German resistance, but an outpost line designed to hold the attackers, and the miners, a long way back from the main defence. Furthermore, by the time of the most celebrated British mining success at Messines in June 1917, better fighting means and methods had been developed

Sapper William Hackett, a coal miner from Mexborough, South Yorkshire, was the only tunneller to be awarded the Victoria Cross underground during World War I. He enlisted at the age of 43 in November 1915, when age and fitness requirements were relaxed for experienced miners. His award was made posthumously after the Germans detonated a large mine at Givenchy on 27 June 1916, when Hackett repeatedly refused to leave a man trapped 9m underground, saying that he could not leave his mate, until the tunnel collapsed, burying both men alive. His Victoria Cross is displayed at the Royal Engineers Museum, Chatham. (Author)

The last of 183rd Tunnelling Company before disbandment, Le Rosel, Somme, February 1919. The officer, 2nd Lieutenant William Pauls, had just received the Military Cross for removing mines and booby traps in 1918. The tunnellers wear a red 'T' on the upper arms. (Author)

This image is from an *In memoriam* card commemorating Johann B. Häusler, by occupation a bricklayer from Buchbach, Bavaria, killed on 9 June 1917 during the battle of Messines while serving in the 3. Bayerische Mineur-Kompagnie. (Author)

and mining was too blunt to weapon to fit in with the Allies' new tactics of all-arms cooperation. As mobility was restored to the Western Front in 1917–18, mining troops were rapidly shifted to other engineering roles. The British and Commonwealth tunnelling companies provided the logistics engineers needed in the advances of the Hundred Days Offensive (8 August–11 November 1918), including retraining in heavy bridging, and removing thousands of booby-trap mines and delayed-action charges.

The exact circumstances of the Western Front during 1914–18 have never been repeated, but even if they had been, experience meant that armies would not react in the same way. In a 1929 lecture, Harvey, the British Inspector of Mines at GHQ during 1916–18, who before the war had warned of mining's future use, now cautioned his fellow Royal Engineers to do everything they could to avoid it taking place in a future war. Defensive underground shelters would always be needed, he said, but the 'blow from below' was far too slow and inflexible a method (Harvey 1929: 548). In less than a decade, defensive shelters were indeed being prepared to protect civilian populations from aerial bombardment.

It only remains to pay tribute to the miners. Long accustomed to working in constant danger and to trusting their mates with their lives, they fought their private war by hand, by machinery, or by enduring hours of silent listening. Their deaths came from poisoning by mine gas or burial forever from sudden explosions deep beneath the ground.

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Title-page illustration: Mine explosion in the enemy lines, Champagne, France, *c.*1915–16. Troops holding sectors in mining areas of the front lived in an atmosphere of continual uncertainty and fear of a sudden and catastrophic explosion. Mines robbed them of the security that trenches and dugouts provided and all noises became suspect. (Chronicle/Alamy Stock Photo)